ASD TECHNICAL REPORT 61-720

HUMAN PERFORMANCE AS A FUNCTION OF THE WORK-REST RATIO DURING PROLONGED CONFINEMENT

OSCAR S. ADAMS

LOCKHEED-GEORGIA COMPANY

W. DEAN CHILES

AEROSPACE MEDICAL LABORATORY

NOVEMBER 1961

BEHAVIORAL SCIENCES LABORATORY
AEROSPACE MEDICAL LABORATORY
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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Lockheed-Georgia Company, Marietta, Georgia
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PROJECT No. 1710
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AEROSPACE MEDICAL LABORATORY
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

1100 - March 1962 - 24-993 & 994

FOREWORD

This report summarizes research on prolonged human performance as a function of the work-rest cycle conducted by the Human Factors Research Department, Operations Research Division, Lockheed-Georgia Company. The 4-day and 15-day studies were under the general direction of Dr. Oscar S. Adams, Project Director, Dr. Jack A. Kraft,* Department Manager, and Mr. Robert D. Roche, Division Engineer; the Control Group study was under the direction of Dr. James T. Ray.**

The work was supported by the Behavioral Sciences Laboratory, Aerospace Medical Laboratory, Aeronautical Systems Division, under Contract Nos. AF 33(616)-6050 and AF 33(616)-7607, Project No. 1710, "Training, Personnel and Psychological Stress Aspects of Bioastronautics," Task No. 171002, "Performance Effects of Environmental Stress." Dr. W. Dean Chiles, Chief, Environmental Stress Section, Training Research Branch, Behavioral Sciences Laboratory, served as Task Scientist and consultant.

The maintenance of the experimental apparatus was assigned to the Lockheed-Georgia Electronics and Armament Systems Laboratory, with Mr. Fred R. Willard serving as Department Manager. The work was under the supervision of Mr. James N. Howard, assisted by Mr. Arthur J. Pittock* and Mr. Thomas B. Miller. The preparation of all meals served to the subjects during the 15-day tests was under the supervision of Mrs. Nancy Garrard.

The authors wish to express their appreciation to all members of the Lockheed project team who participated in the test program and in the preparation of this report. They would like to recognize, in particular, the assistance of Dr. Raphael B. Levine, Dr. James T. Ray, Mr. O. Edmund Martin, Mr. Richard P. Smith, Mr. Thomas W. Meighan, Jr., Mr. George D. Hayes, Mr. Phil T. Dunning and Mr. Albert S. Howe. Indebtedness is acknowledged to Mr. Sheldon R. Dickstein, Engineering Artist, and Mrs. Marie F. Hutchins, Department Secretary, for their assistance in preparing the manuscript for publication. Our appreciation is extended to Dr. Earl A. Alluisi for his advice and contribution during the preparation of this report.

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ABSTRACT

The purpose of this study was to investigate the feasibility of using a 4-hours-on-duty and 2-hours-off-duty schedule in the operation of advanced aerospace systems. Two B-52 combat-ready crews were confined for 15 days in a simulated advanced system crew compartment and were tested with a battery of five performance tasks and four psychophysiological measures. Data obtained during two 15-day testing periods are summarized in the main body of this report.

Additional performance data obtained from five studies using college student subjects are presented in appended sections of this report. These results are based on four 96-hour investigations (two with a 4-on and 2-off schedule and two with a 6-on and 2-off schedule) and one 120-hour control group study (4 hours per day, 5 days per week, for 6 weeks).

With proper control of selection and motivational factors, crews can work effectively for periods of at least two weeks and possibly longer using a 4-on and 2-off work-rest schedule.

PUBLICATION REVIEW

Walter F. Grether

WALTER F. GRETHER
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INTRODUCTION

For most of our present man-machine systems which are maintained in a continuous operational status for periods of several days or more, it is possible to provide sufficient numbers of personnel and quantities of supplies to obviate the imposition of overly demanding work schedules as a routine operating procedure. However, if the current trend in planning continues to increase the length and complexity of aerospace and satellite missions, power and weight factors will become increasingly important as determiners of vehicle capabilities. We are concerned in this report with the capabilities of systems in which (a) power (and hence weight) is a critical problem, (b) projected mission durations are in excess of 72 hours and (c) there is a requirement for continuous operator performance of one or more tasks. Clearly, situations of this sort are only minimally amenable to solution by approaches which involve additional shifts of personnel. And this will continue to be the case at least until the point is reached at which it is feasible, both technologically and economically, simply to add more power if more personnel (weight) are required for a system.

Within this framework, the most obvious alternative to increasing the crew complement and vehicle size is to exact the maximum amount of operator effort that will still insure the requisite levels of operator efficiency and probabilities of mission accomplishment. Our initial efforts in attacking this approach to the problem grew out of a rational analysis of the nature of the tasks to be included in aerospace vehicles. Our conclusion was that the operator in such vehicles would be required to perform three major functions: (a) monitoring of system status information, (b) making simple mental calculations and (c) discriminating differences in visual patterns. Since the characteristics of specific manifestations of such tasks suggest that monotony and boredom would be important determiners of operator proficiency, we felt that the determination of the optimal duration of work periods was prerequisite to further research. Toward this end, the performance of 16 subjects on four different duty-period and rest-period schedules (2-hours work/2 hours rest; 4 work/4 rest; 6 work/6 rest; and 8 work/8 rest) were examined over a 96-hour period of time. The results of this study (reported in detail by Adams & Chiles, ref. 2) suggested that, for tasks involving the above described functions, the 2-hour and 4-hour work shifts were superior as indicated by subject preferences and overall indices of subject adjustment to the experimental programs.

Subsequently, two studies (described in Appendix I) were conducted to examine greater proportions of time at work. Specifically, a group of subjects was required to follow a 4-hours work/2-hours rest schedule for 96 hours, and a second group of subjects followed a 6-hours work/2-hours rest schedule for 96 hours. Although the performance data did not demonstrate either schedule to be superior to the other, there was evidence that severe decrements would probably result from prolongation of the experimental period in the case of the 6-2 schedule but probably not in the case of the 4-2 schedule. We observed, for instance, that the subjects on the 6-2 schedule averaged less than 4 hours of sleep per day whereas those on the 4-2 schedule averaged about 5-1/2 hours of sleep per day. Unless there are some conditions of space flight such as weightlessness which will prove to reduce sleep requirements, we consider the 4 hours of sleep obtained by subjects on the 6-2 schedule to be inadequate over prolonged time periods. On the other hand, 5-1/2 hours of sleep per day might maintain the operator in an alert condition for a long time.*

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*Other studies of somewhat less direct relevance to our investigations have been reviewed elsewhere. (Ray, Martin & Alluisi, ref. 5)

These studies provided the groundwork for the more extensive experiments which are the main topic of this report. In addition to the extension of the period of investigation, we felt that three other experimental refinements should be introduced. First, for practical reasons, the subjects in our previous studies were college students whereas the use of Air Force personnel would be more to the point. Second, again for practical reasons, previous subjects were permitted considerably more physical freedom than would be afforded by aerospace vehicles. And third, our previous procedures involved direct experimenter contact with the subjects during portions of the 96-hour experimental periods. In implementing these refinements, the cooperation of the Strategic Air Command was secured in providing operational crews as subjects. Subjects were confined to the crew compartment (figure 1) throughout the investigation. Communications with the "outside world" were prohibited and those with the experimenters were restricted to intercom messages of direct relevance to the "mission."

Our decision to use a 15-day period of confinement was based on two primary considerations. First, this length of time extends well beyond the point up to which the individual can be expected to compensate for serious degrees of fatigue-induced deterioration by the expenditure of additional effort. Second, at least at the beginning of the study the individual would be expected to consider a 15-day period as a rather long time—and hence not a trivial experience—if the situation were to prove unpleasant. Several practical factors such as economy and maintenance of equipment precluded the use of a longer period at the time the study was conducted.

METHOD

SUBJECTS

The subject sample consisted of two B-52 combat crews from the Strategic Air Command. The first crew (Group A) to be tested was composed of five men (four officers and one enlisted man), and the second crew (Group B) was composed of six men (five officers and one enlisted man). Both crews ranged in age from 26 to 43 years; their heights ranged from 5 feet 7 inches to 6 feet 2 inches; and their weights ranged from 148 to 195 pounds. When Group A reported for the test we discovered that it was not a true volunteer crew; because of the limited time available for selection, this crew had been recalled from leave in order to participate in the program. Group B, however, had volunteered for the assignment.

Members of both crews had been flying together for over 12 months. The total flying hours logged by individual crewmembers averaged 2732 hours and ranged from 960 to 4200 hours. The maximum number of hours flown during any 14-day period ranged from 32 to 80 hours with an average of 50 hours. The average duration of the longest single mission was approximately 19 hours; individual reports ranged from 10 to 28 hours. An interrogation of the members of the second crew revealed that while they knew that a previous crew had been tested they were unaware of any details of the test situation or the outcome.

TEST FACILITY

Subjects were tested in an advanced system crew compartment mock-up which has been described in a previously published report (Adams, ref. 1). An artist's view of the compartment as modified for use in this study is shown in figure 1. In its present configuration it is divided into three sections: a 5-station work area, a leisure area, and a sleeping area. The total volume is approximately 1100 cubic feet, half of which is devoted to the work-station and leisure areas, and the other half to the sleeping area.

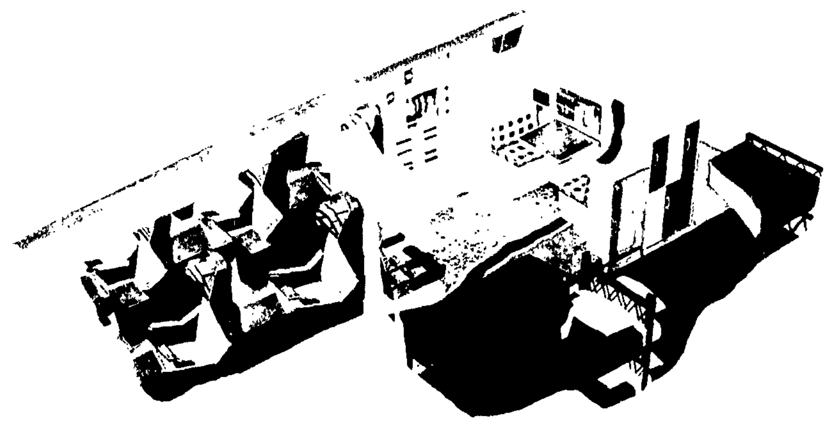

Figure 1. Cutaway view of advanced system crew compartment mockup.

While on duty, subjects occupied an assigned position in the work-station area. During off-duty hours they were restricted to the leisure area or to the adjacent 6-bunk sleeping area. The work-station and leisure areas were adequately and comfortably illuminated at all times. The sleeping area was maintained in a semi-darkened condition; its sole illumination was provided by two low-intensity light sources located at floor level. A system of small speakers located at different points throughout the compartment was used to present white noise at a continuous level of approximately 85 decibels in order to mask all outside sounds.*

EXPERIMENTAL DESIGN

The two crews were tested separately on an around-the-clock schedule of 4 hours duty and 2 hours rest for a period of 15 days (360 hours). For example, on a typical day, subjects S-1, S-2, S-3 and S-4 would be on duty from 0930 to 1130. At 1130 subjects S-1 and S-2 would be replaced by subjects S-5 and S-6, and at 1330 subjects S-1 and S-2 would return to duty to replace subjects S-3 and S-4. In the case of Group A, which contained only 5 subjects, the rotation of duty periods was the same except that, since there was no subject 6 in this group, during one third of the 2-hour sub-periods there were only three men on duty. Using a six-man test group this schedule makes it possible to keep four work stations occupied continuously except for a brief time, less than a minute, during which the two subjects who have been on duty for four hours are replaced. At the end of 15 days each subject had accumulated a total of 240 hours of work.

*Audiograms, taken on Group B subjects before and after the 15-day exposure, revealed no evidence of hearing losses. The meaning of this finding is uncertain in that, as members of a B-52 crew, these subjects were routinely exposed to even higher levels of jet engine noise.

TASK PROGRAM

A battery of five performance tasks designed to test psychological functions such as mental computation, pattern discrimination, monitoring and vigilance was used throughout the tests. The tasks were displayed on an 11-by-28-inch panel (see figure 2) which was mounted at each work station in the crew compartment. The specific tasks have been discussed in detail in previous reports (Adams, ref. 1; Adams & Chiles, ref. 2; and Adams, Levine & Chiles, ref. 3) and are briefly described in Appendix III.

Figure 2. Subject's view of performance panel located at each of the work stations. The arithmetic computation task is presented by means of the 9 numerical indicator tubes located along the lower portion of the panel. The pattern discrimination task is presented by means of the 6 by 6 array of lights located in the lower left corner. The 4 meters located along the upper portion are used to present the probability monitoring task. Ten warning lights (5 red and 5 green) are located in pairs on both sides and in the middle of the panel.

A 2-hour task program, shown in figure 3, was presented 180 times during each of the

TASK	MINUTES
	000 015 030 045 060 075 090 105 120
Warning Lights	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx (000–120)
Auditory Vigilance	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx (000–120)
Probability Monitoring	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx (015–105)
Arithmetic Computation	xxxxxxxxxxxxxxxxxx (015–060)
Pattern Discrimination	xxxxxxxxxxxxxxxxxx (060–105)

Figure 3. Basic two-hour performance task program.

two 15-day tests. It consisted of a 30-minute low performance period and a 90-minute high performance period. From the subject's point of view there was no break between repetitions of the program since the auditory vigilance and warning lights were presented continuously at each work station. An amber light on each subject's panel signaled that the arithmetic and probability monitoring tasks would begin in 1 minute; another amber light signaled that the arithmetic task was over and that the pattern task would begin in 30 seconds. Although the subjects were told that their performance was being scored continuously, they were actually scored only during the 90-minute high performance period.

PSYCHOPHYSIOLOGICAL RECORDING

Four psychophysiological measures (skin resistance, skin temperature, heart rate, and respiration rate) were selected for use in this study. These have been discussed in a previous report (Adams, Levine & Chiles, ref. 3) and are described briefly in Appendix III. The sensing elements for heart rate and respiration rate were applied as a harness attached to an elastic belt fastened about the subject's waist. Skin resistance was picked up from forearm and finger electrodes, and skin temperature was measured by a thermistor on the forehead. Electrical leads from the sensors were joined to form a cable which terminated in a multi-pin plug; this plug was inserted into a receptacle located in the seat of the subject's work station.

Data were recorded from two subjects simultaneously. Voltages proportional to the meter deflections of the skin resistance, heart rate, and respiration movement instruments were recorded on six channels of an 8-channel Offner Type-R Dyncgraph. A seventh channel indicated on the record the exact 5 minutes during which heart beats were being tallied on a separate counter for each of the two subjects. Each 15 seconds the experimenter manually recorded from the appropriate meters the skin temperature level to the nearest 0.01° C and the skin resistance level to the nearest 1000 ohms. Heart-beat counter readings were recorded at the end of the 5-minute recording interval. By this means, the data points were tallied and ready for reduction to 5-minute-interval values as soon as they were obtained in the case of skin temperature level and fluctuation, skin resistance level, and heart rate level. The remaining four measures (skin resistance fluctuation, heart rate fluctuation, and respiration rate level and fluctuation) were reduced to interval values as they were subsequently read from the oscillograph charts.

As indicated in figure 3, the task program followed a basic 2-hour schedule in which the subject was presented a sequence of 15 minutes of low-demand monitoring, 45 minutes of high-demand monitoring plus the arithmetic task, 45 minutes of high-demand monitoring plus the pattern discrimination task, and 15 minutes of low-demand monitoring. During each of these four subdivisions of the task program, and approximately at their time-centers, five minutes of psychophysiological data were recorded in the manner described above. A total of eight 5-minute samples was recorded during each one-half of the total number of 2-hour duty periods. The recording periods for individual subjects were staggered so that records could be obtained both early and late in the work periods. For example, if a given subject was on duty during periods (2-hour units) 1 and 2, 4 and 5, 7 and 8, 10 and 11, etc., his psychophysiological data were recorded either during periods 1, 5, 7, 11, etc., (i.e., early-late) or during periods 2, 4, 8, 10, etc., (i.e., late-early). For this report, data are analyzed for only the 5-minute section of record obtained while the subject was performing the arithmetic and four monitoring tasks simultaneously.

ORIENTATION AND TRAINING

The two flight crews reported to the laboratory on their respective reporting dates which in both cases was a Tuesday. They were welcomed by the local Air Force Plant Representative, the ASD Project Officer, and Lockheed personnel. Most of the first day was devoted to a general briefing concerning the purpose of the research project and a description of the test plans. Considerable time was spent discussing the objectives of the study and the importance of obtaining quantitative data relating to the problem of optimal work-rest schedules. In general, an informal relationship was established between the crew and the experimenters. Questions and comments were encouraged, and every attempt was made to dispel any doubt, fear, or mystery that may have developed concerning the nature of the project.

On the second day of orientation the crew was divided into two subgroups of three men each. During the morning one group received instructions and two hours of experience on the operation of the performance tasks. The other group was briefed on the objectives of the physiological measures and learned to attach properly the various electrodes. The two subgroups alternated for the afternoon period.

The third day consisted of further task training and a short interview with each subject. The training consisted of performing the tasks in accordance with the 2-hour schedule shown in figure 3. The purpose of the interview was primarily to obtain information about items such as the subject's age, marital status, flight experience, the existence of any anticipated family emergencies or any particular sources of worry. At the same time, each subject was given, if he wanted them, a supply of postcards on which he could write messages to his family. These were collected by the experimenter together with instructions from the subject concerning the date they should be posted. A staggered schedule of task training and interviews was followed so that by the end of the day each subject had repeated the task program three times for a total of six hours of experience.

TESTING

The crews reported to the Laboratory at 0800 hours on a Friday and spent approximately one hour stowing their personal equipment in individual lockers located in the crew compartment. They had been instructed to bring only the minimum amount of clothing and toilet articles required for the 15-day confinement. After all equipment had been stowed, a short pretest briefing was held to answer any last-minute questions. Testing commenced at 0930 hours and continued until 0930 hours on the Saturday, 15 days later.

Incidental to the actual performance testing, the subjects had been given detailed instructions concerning the following regulations and procedures related to the test conditions:

(a) For Group A, a clearly audible buzzer was sounded in the sleeping quarters 15 minutes prior to the time a pair of subjects was scheduled to go on duty. In order to stop the buzzer, it was necessary for one man to get out of his bunk and actuate a toggle switch. The 15-minute period allowed sufficient time for both subjects to dress and to put on their physiological harnesses. Exactly on the odd half-hour, the experimenter sounded three short blasts on the wake-up buzzer as a signal to change stations. The identical procedure was followed with the second crew except that the wake-up buzzer was not sounded until 10 minutes before the beginning of a work session.

(b) All meals were furnished by the Laboratory and were placed in a food compartment in the leisure area of the mock-up at specified times. The daily menus were planned by Miss Beatrice Finkelstein, Biospecialties Section, Physiology Branch, Biomedical Laboratory. The meals were of the foil-pack variety having been precooked, packaged, and frozen several days before the beginning of the tests. At a predetermined time the meals for two subjects were removed from the freezer, thawed, heated, and placed in serving trays which were then placed in the two-way food compartment. Canned fruit juices, coffee, tea, and milk supplemented the regular menu.

For the first crew (Group A) a meal was served every 2 hours over a period of 16 hours per day to the two subjects coming off duty. For one pair of subjects the breakfast, lunch, and dinner times were 0530, 1130, and 1730 hours, respectively. For another pair the times were 0730, 1330, and 1930 hours; for the third pair they were 0930, 1530, and 2130 hours.

Because the time required to eat meals on this schedule consumed a significant portion of 3 of the 4 daily rest periods and because several members of the first crew complained later that they had difficulty in going to sleep immediately after a meal, the feeding schedule was changed for the second crew (Group B). Instead of eating immediately following a 4-hour work period, Group B subjects were permitted to eat during the 30-minute low performance portion at the middle of the 4-hour work period. Prior to the beginning of the test one subject from each pair was designated to leave his work station as soon as the pattern task had ceased, remove the two food trays from the food compartment, and bring them to the work stations. When the meal was completed, or before the arithmetic task commenced, the other subject returned the trays to the food compartment. The subjects were told that they were responsible for the monitoring tasks even though they were eating.

(c) During the 30-minute low-performance period of the task program, subjects were allowed to leave their stations to use the toilet facility provided they requested permission from the aircraft commander (or copilot, if the A/C was not on duty). The crew had been instructed that at least three stations must be occupied at all times during the low performance period.

(d) Certain ground rules were established with respect to the procedures and use of the intercom system. The test crew was designated as "Operation 360" and the experimenter station was designated as "Homebase." During the pre-test orientation, it was specifically requested that intercom conversation be kept to a minimum and that no calls be made to Homebase unless there was an apparent malfunction in the equipment or in case of an emergency.

(e) Subjects were informed that with the beginning of the 15-day confinement period the test would be considered a closed-system operation. Their only contact with the "outside" world would be with the experimenter by means of the intercom. They were assured, however, that any given subject would be released from the test in case of sickness or an emergency at home.

(f) The food service unit located in the leisure area was well stocked with canned fruit juices, soup, toddy, instant coffee, tea, and an assortment of gum, candy, and nuts. These could be consumed ad libitum.

On the Sunday following the termination of the confinement period, each subject was interviewed privately to get his reactions to a series of questions relating to his attitudes toward the experiment and experimenters, his adjustment to the work schedule, his opinions as to task difficulties and any particular subjective reactions he might have experienced.

RESULTS

PERFORMANCE MEASURES

The results obtained on each of the five performance tasks have been analyzed in terms of means of measurements made on the different days (between-day trends) and in terms of means of measurements made at different times of day (within-day trends). In order to obviate making any assumption as to the forms of the sampling distributions, nonparametric tests have been used in the statistical analyses.

Between-Day Trends

The mean levels achieved on the 7 performance measures by the 11 subjects during each of their 120 two-hour work periods are presented in figure 4. Since it was necessary to stagger the work periods of individual subjects, the time of performance may have differed by two hours

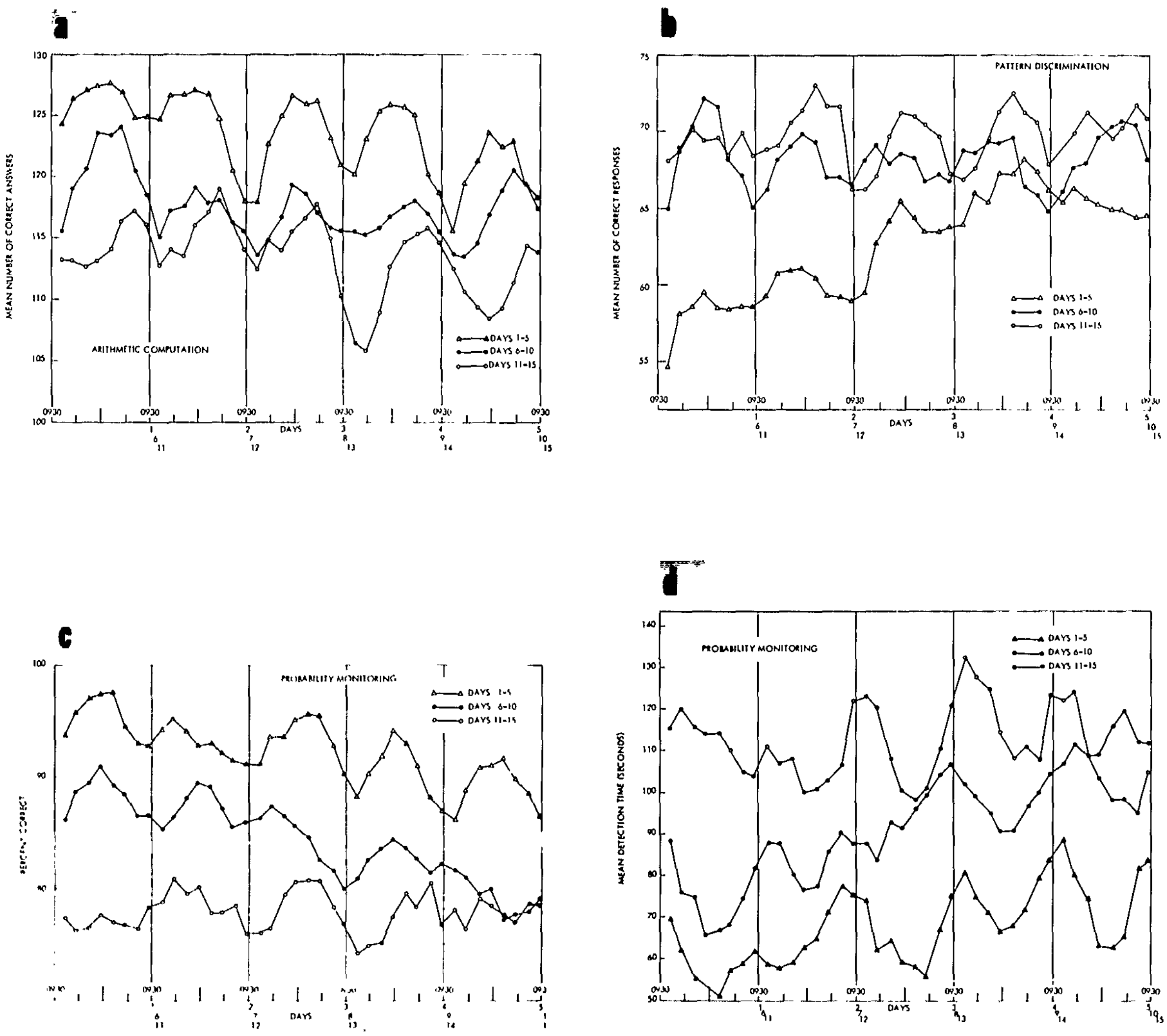

Figure 4 (A through D). Mean levels achieved on the measures of task performance. Curves are based on performance of all 11 subjects during each of the 8 presentations of the 2-hour task program per subject per day.

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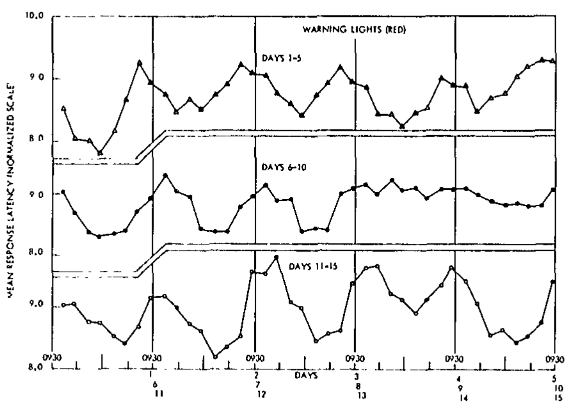

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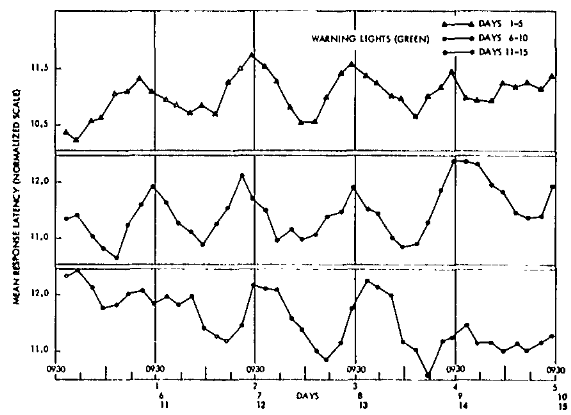

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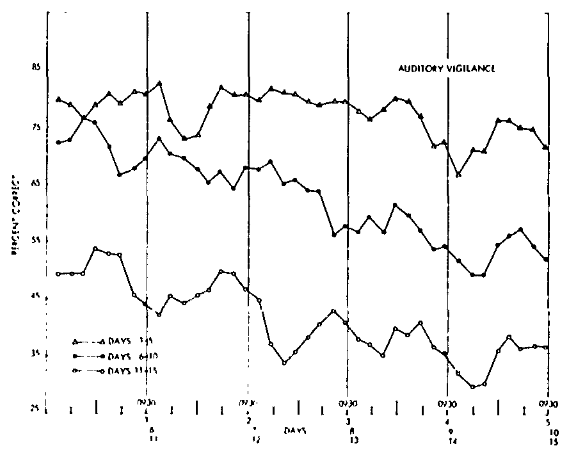

Figure 4 (E through G). Mean levels achieved on the measures of task performance. Curves are based on performance of all 11 subjects during each of the 8 presentations of the 2-hour task program per subject per day.

of clock time. The location of each point with reference to the time scale (abscissa) was determined by averaging the individual clock times. In order to show conveniently the relation of between-day trends to within-day trends, the 15-day curves have been divided into three 5-day segments.

Friedman's analysis of variance test for ranked data (ref. 4) was used to determine the significance of the differences observed among the daily levels of performance. This analysis was performed using the data for each group separately and for both groups combined. The resulting chi-squares, 3 for each performance measure, are given in table 1.

TABLE 1

Analysis of Variance by Ranks: Daily Levels of Task Performance

Task Measure	Group	Chi-square	p-level*
Arithmetic Computation	A	44.58	.001
(Number of Correct Answers)	B	17.67	--
	A+B	44.64	.001
Pattern Discrimination	A	12.38	--
(Number of Correct Responses)	B	62.31	.001
	A+B	50.17	.001
Probability Monitoring	A	51.31	.001
(Percent Correct)	B	33.55	.003
	A+B	72.26	.001
Probability Monitoring	A	56.14	.001
(Detection Time)	B	39.28	.001
	A+B	82.14	.001
Warning Lights Monitoring	A	37.41	.001
(Response Latency to Red Lights)	B	10.83	--
	A+B	14.08	--
Warning Lights Monitoring	A	35.78	.002
(Response Latency to Green Lights)	B	14.44	--
	A+B	19.88	--
Auditory Vigilance	A	54.70	.001
(Percent Correct)	B	60.61	.001
	A+B	110.69	.001

*df = 14. Note: With the exception of Pattern Discrimination, a significant Chi-square denotes a decrement; Group B and the combined data for Groups A and B showed improvement on the pattern task.

The differences among Group A's daily levels of performance are sufficiently large to reject the null hypothesis on 6 of the 7 measures. In each case the trend is toward a decrement in performance. Group B's performance, on the other hand, contains a significant between-day effect on only 4 of the 7 measures. On 3 of these the level of performance decreases with time, while on one (pattern discrimination) it improves. When the data for the subjects in both groups are combined, the differences among daily performance levels are significant for all tasks with the exception of warning lights monitoring.

The analysis shown in table 1 reflects the extent to which the temporal trends of performance for individual subjects were in agreement. In this respect a clearer indication of the differences among the subjects is given in table 2 which shows the correlations (rho) obtained between the rank-ordered means of daily performance and the days of the study. Thirty of the 35 coefficients computed from the Group A data have a value which is sufficiently large to reject the null hypothesis at the .05 level using a one-tailed test. Twenty-eight of these reflect a trend toward decreasing performance, and 2 indicate an improvement. Individual performance in Group B, on the other hand, correlated significantly with time in only 29 out of the 42 cases; 19 of these indicated a decrement, and 10 were in the direction of improvement.

TABLE 2

Correlation (Rho) of Each Subject's Rank-Ordered Daily Performance Level With Days of the Study

Group	Subject	Task Measure						
		Arith.	Patt.	Prob. (%)	Prob. (Time)	W-Lites (Red)	W-Lites (Green)	Audio
	S-1A	-.84	-.77	-.98	.96	.73	.93	-.96
	S-2A	-.94	-.50	-.90	.87	.94	.93	-.84
A	S-3A	-.52	.91	-.59	.78	.11	.30	-.94
	S-4A	-.48	.62	-.78	.85	.34	.25	-.50
	S-5A	-.96	.26	-.90	.88	.86	.78	-.88
	S-1B	.38	.16	-.84	.93	.68	-.09	-.96
	S-2B	-.87	.92	-.52	.55	-.64	-.53	-.92
B	S-3B	-.04	.99	-.28	.50	.59	.57	-.91
	S-4B	-.83	.99	-.19	.30	-.78	-.50	-.63
	S-5B	.10	.96	-.04	-.06	-.21	-.08	-.50
	S-6B	-.51	.96	-.54	.75	-.60	-.34	-.96

.05 Level: rho = .44 (one-tailed test)
.01 Level: rho = .62 (one-tailed test)

The differences observed between the two test groups are further illustrated in figures 5 and 6. The daily means and standard deviations of arithmetic scores for each group are shown in figure 5; the same treatment of pattern task scores is presented in figure 6. There are several features that are common to both plots. First, Group B consistently maintains a higher level of performance than Group A. Second, the differences between the two groups become larger with successive days of the study. Third, the variability of Group A's scores is much larger than that of the Group B data. And fourth, the scores for both groups increase in variability with time.

Inspection of the performance vs time correlations for individual subjects on all 7 task measures (table 2) reveals that the performance of two subjects, both in Group B, was only minimally affected by the conditions of the study. The performance of one subject (S-5B) decreased on only one task (auditory vigilance), improved on one (pattern discrimination), and remained steady on the other three. In the case of the other subject (S-4B), performance decreased significantly on two tasks (arithmetic and auditory vigilance), improved on two (pattern discrimination and warning lights), and showed no significant change on the remaining one (probability monitoring).

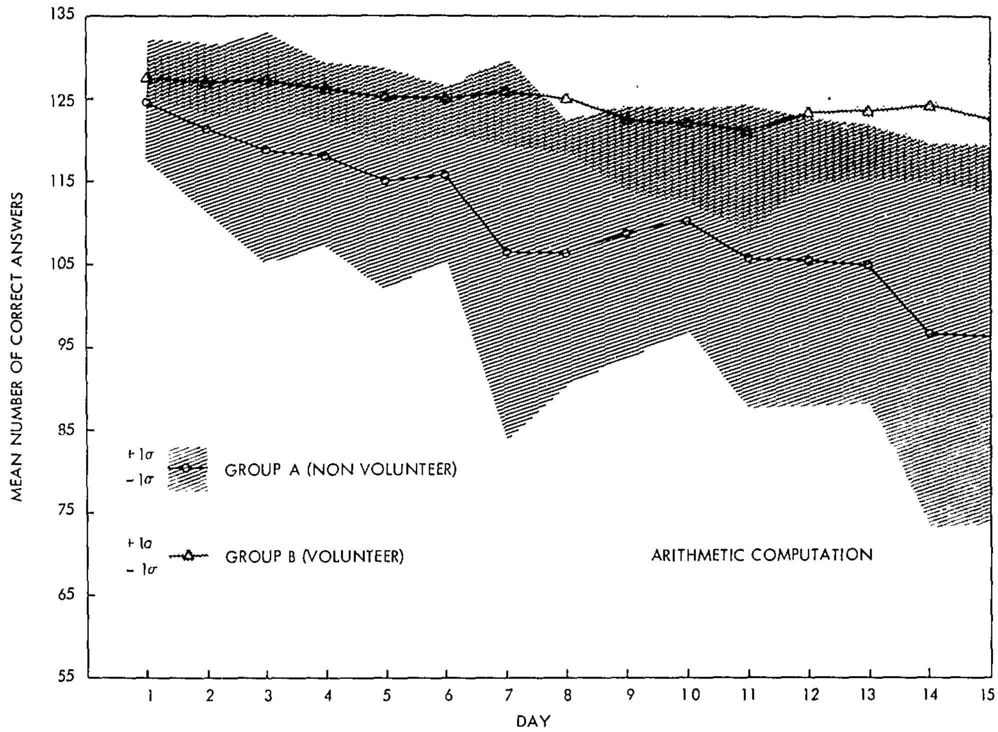

Figure 5. Comparison of Groups A and B in terms of the mean and standard deviation of arithmetic computation task scores for each day of the study

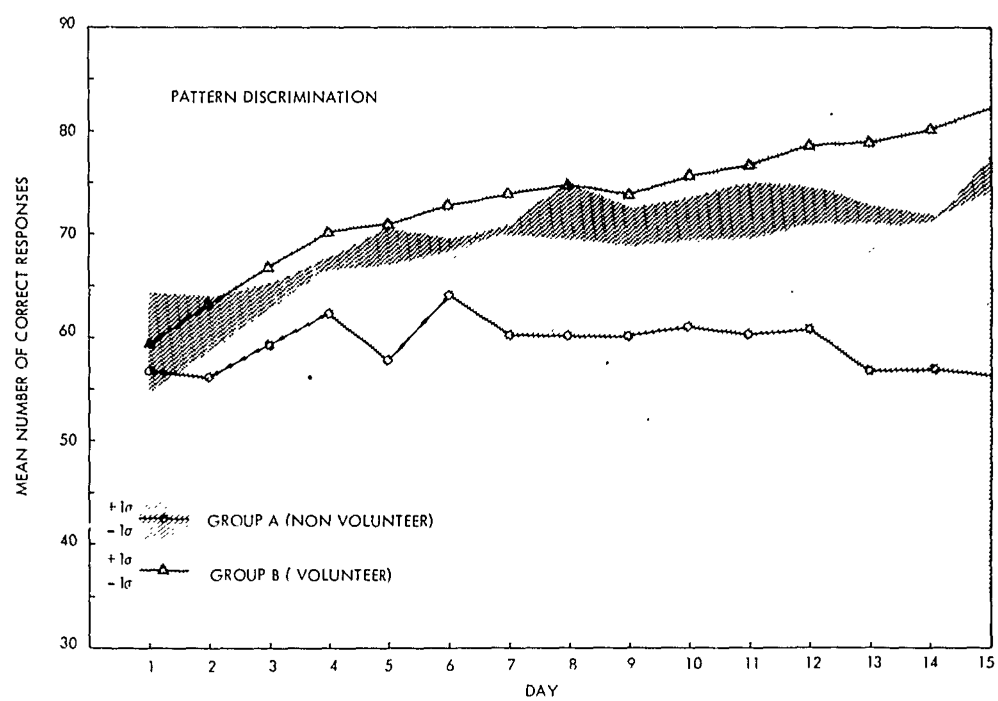

Figure 6. Comparison of Groups A and B in terms of the mean and standard deviation of pattern discrimination task scores for each day of the study

Within-Day Trends

One of the most prominent features of the curves shown in figure 4 is the reasonably consistent within-day change, or diurnal variation, in performance that continued over the 15-day period. This variation is still evident in figure 7 in which the performance of all subjects has been combined on the basis of the eight 2-hour periods per day and plotted for the first, middle, and the last 5-day blocks of experimentation.

Friedman's test was used to determine the significance of the observed differences among the within-day means for each of the three 5-day blocks and for the entire 15-day block. The results of this analysis are given in table 3. A significant within-day effect is present in all task measures when scores are averaged over the entire 15-day period, and in 14 of the 21 separate 5-day blocks.

TABLE 3

Analysis of Variance by Ranks:
Within-Day Levels of Task Performance

Task Measure	Day Blocks	Chi-square	p-level*
Arithmetic Computation (Number of Correct Answers)	1-5	21.20	.01
	6-10	9.83	--
	11-15	19.93	.01
	1-15	24.41	.01
Pattern Discrimination (Number of Correct Responses)	1-5	18.97	.05
	6-10	17.62	.05
	11-15	17.38	.05
	1-15	20.21	.01
Probability Monitoring (Percent Correct)	1-5	13.86	--
	6-10	15.52	.05
	11-15	13.81	--
	1-15	16.04	.05
Probability Monitoring (Detection Time)	1-5	17.27	.05
	6-10	14.21	.05
	11-15	19.24	.01
	1-15	23.61	.01
Warning Lights Monitoring: Red (Response Latency)	1-5	30.20	.001
	6-10	16.00	.05
	11-15	23.55	.01
	1-15	22.76	.01
Warning Lights Monitoring: Green (Response Latency)	1-5	12.73	--
	6-10	20.27	.01
	11-15	12.67	--
	1-15	21.55	.01
Auditory Vigilance (Percent Correct)	1-5	11.30	--
	6-10	14.01	.05
	11-15	12.25	--
	1-15	16.03	.05

*df = 7.

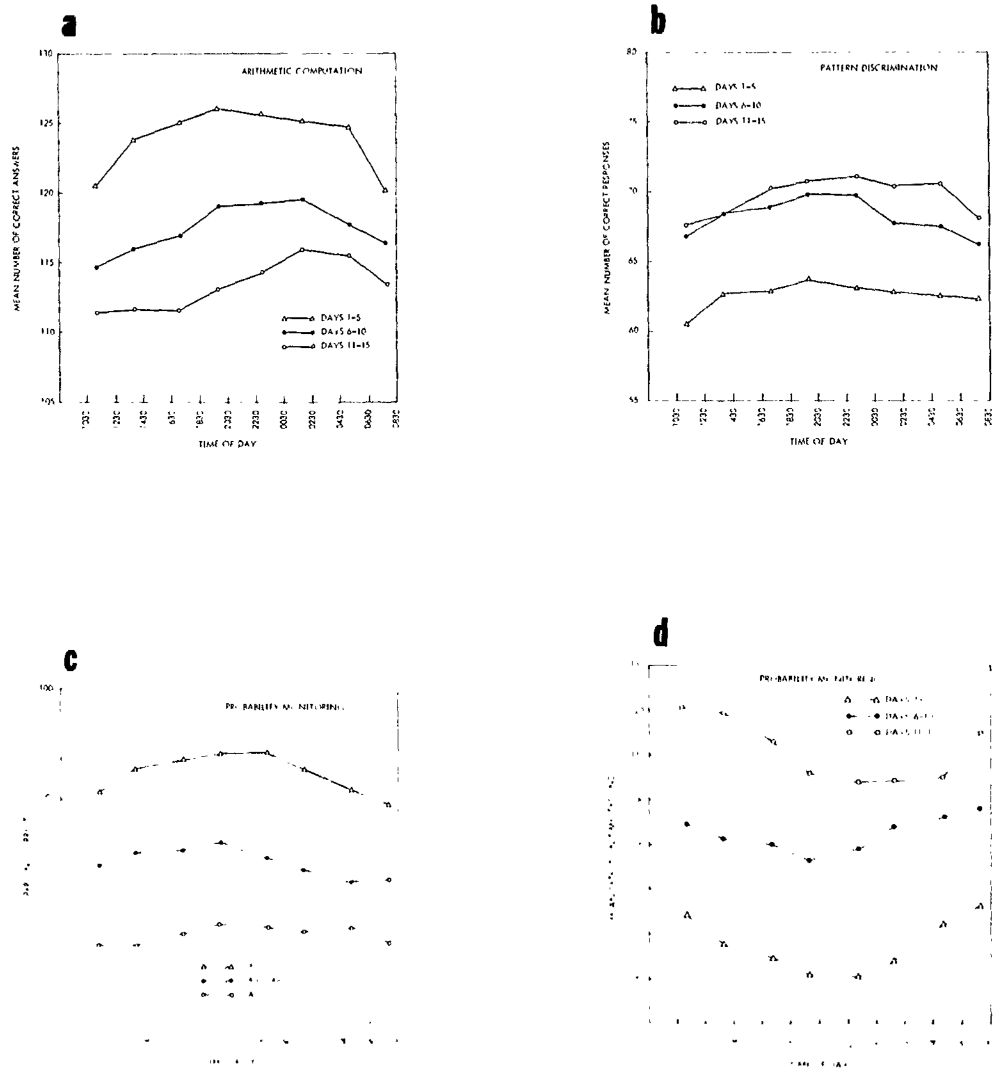

Figure 7 (A through D). Within-day changes in level of task performance

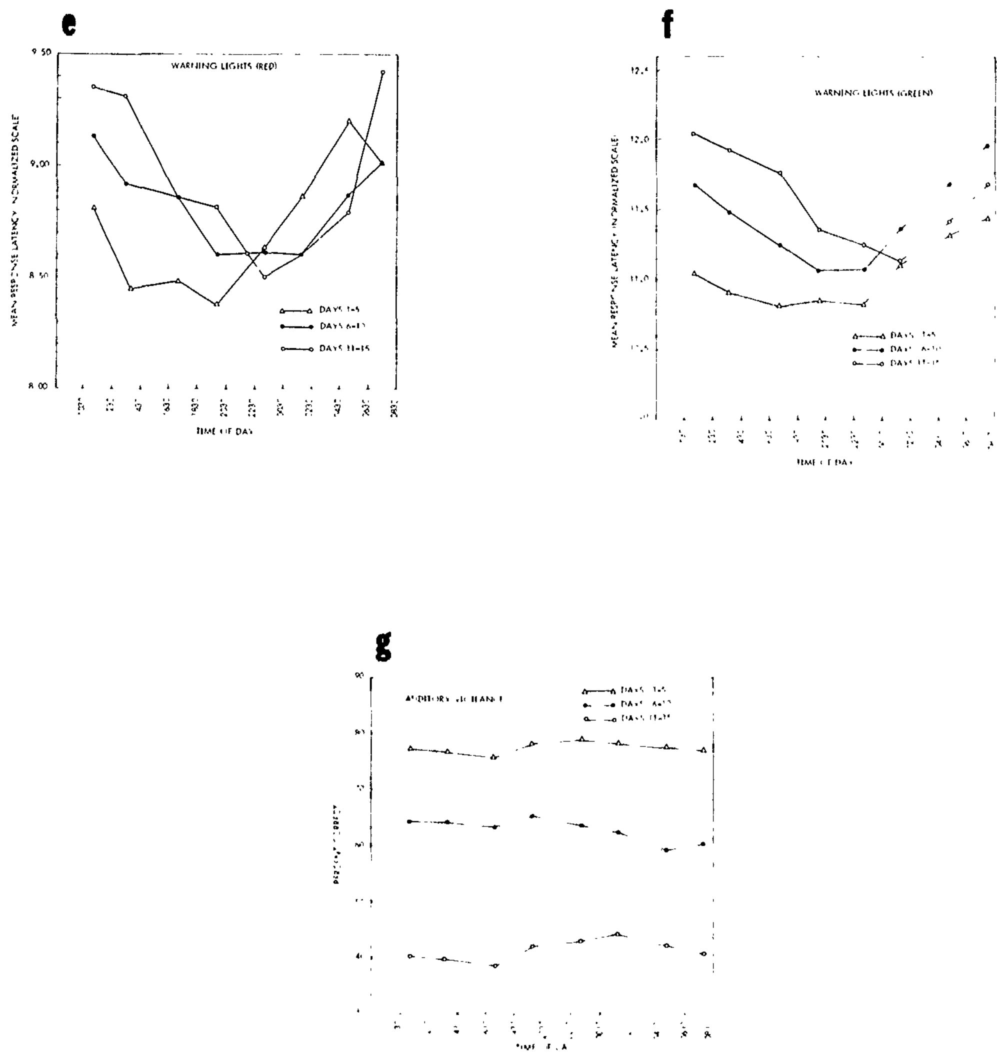

Figure 7 (E through G). Within-day changes in level of task performance

During the first 5 days the time of best performance appears to occur between 1900 and 2200 hours. From this point it begins to decrease, reaching its lowest level during the early to mid-morning hours. There is a further suggestion that the times of maximum and minimum performance shift during the subsequent 5-day blocks. This is shown most clearly in the case of arithmetic computation, pattern discrimination, and warning lights monitoring where the period of best performance appears to shift toward the late evening and early morning hours.

PSYCHOPHYSIOLOGICAL MEASURES

Data for the 4 psychophysiological variables that were sampled while the subjects were performing the arithmetic computation task have been examined for both between-day and within-day trends. The scores were derived differently, however, than those of the performance tasks. As mentioned previously, the procedure followed in collecting the psychophysiological data was to obtain recordings simultaneously on only 2 subjects during a given 2-hour presentation of the task program. This meant that during a 24-hour period the measures were recorded 4 times for each subject at intervals of, alternately, 4 and 8 hours.

Between-Day Trends

Curves for measures of level and of fluctuation for each of the 4 variables are presented in figure 8. Since 2 records were available from each subject during any 12-hour interval of the 360 hours of testing, the data are presented as a 12-hour "rolling mean" score. The ordinate value of each point on the curves shown in figure 8 constitutes the average of 22 scores obtained during 6 successive 2-hour periods; the abscissa value is represented as the mid-point of the 12-hour interval. Although successive means are not independent, i.e., some of their constituent scores are common, any single mean represents the level of measurement obtained for all subjects during that particular 12-hour interval.

In order to test for the significance of a between-day effect, each subject's daily mean level of measurement was assigned a rank between 1 and 15. This set of ranks was used for the analysis of variance test the results of which are given in table 4. A significant between-day effect was obtained for both groups with measures of skin resistance level, skin resistance fluctuation, and heart rate level. A significant difference was also obtained between the daily respiration rate levels of Group A, and of both groups combined. The failure of the Group B differences to attain significance may be partly due to the fact that the analysis included only 4 subjects. The recordings for respiration rate obtained from 2 of the subjects were of such poor quality that they were judged to be unusable.

The correlations which assess the trends in the data of individual subjects are presented in table 5. Of the 42 coefficients which show a significant correlation with time, 36 are in the direction of what might be identified as a decrease in the level of autonomic activation, i.e., an increase in skin resistance and a decrease in all other measures.

Within-Day Trends

The within-day variations in the psychophysiological measures are presented in figure 9. The most prominent trends are observed in the 4 level measurements and in heart rate fluctuation. Among each of these the points of high and low autonomic activation correspond very closely. During days 1 through 5 the period of highest activation occurs in the early evening, but shifts to late evening or early morning in the last 10 days. This is very similar to the shift observed in the measures of task performance.

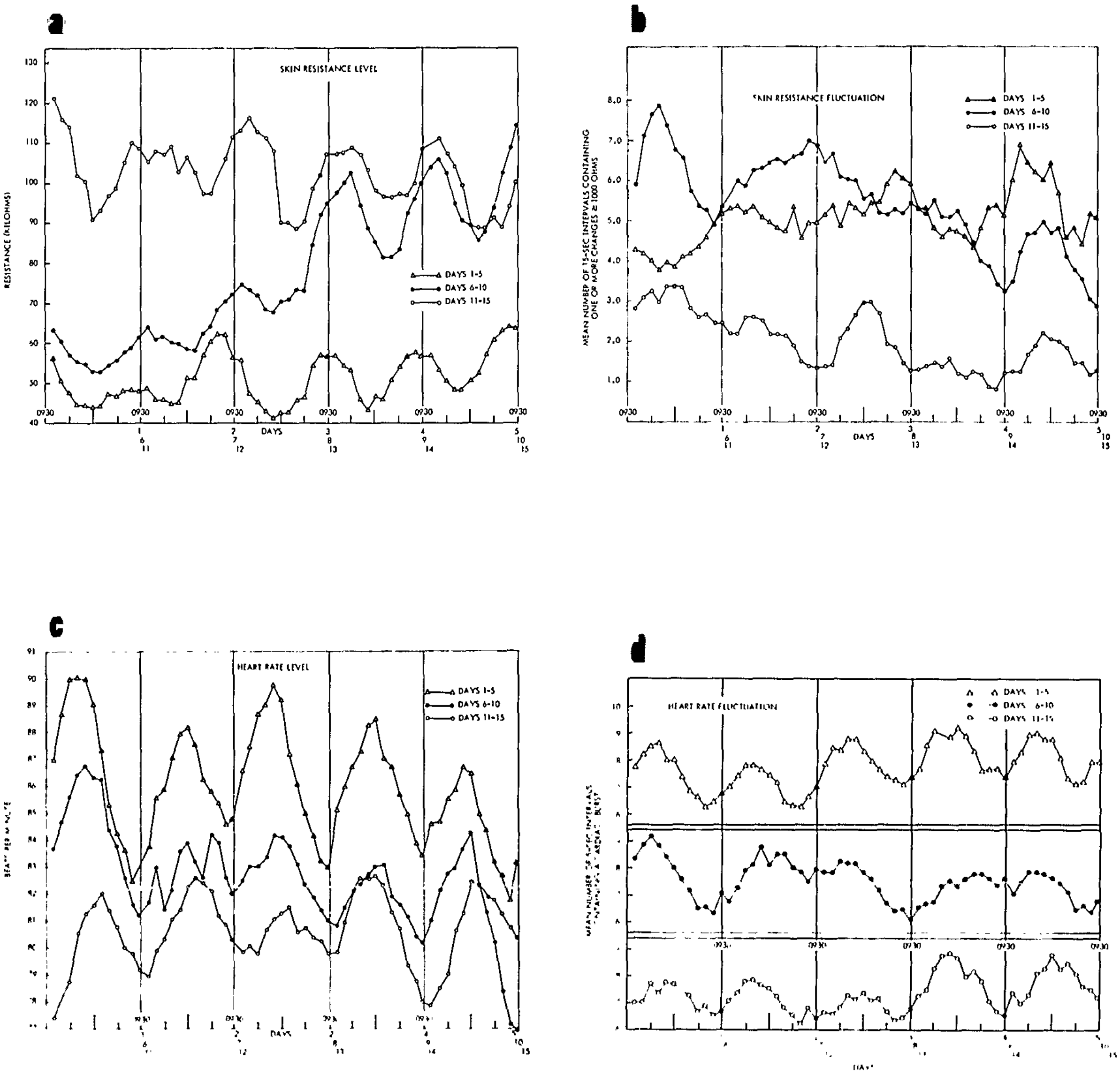

Figure 8 (A through D). Mean level and mean fluctuation for the psychophysiological measures. See text for explanation of method used to derive points on the curves.

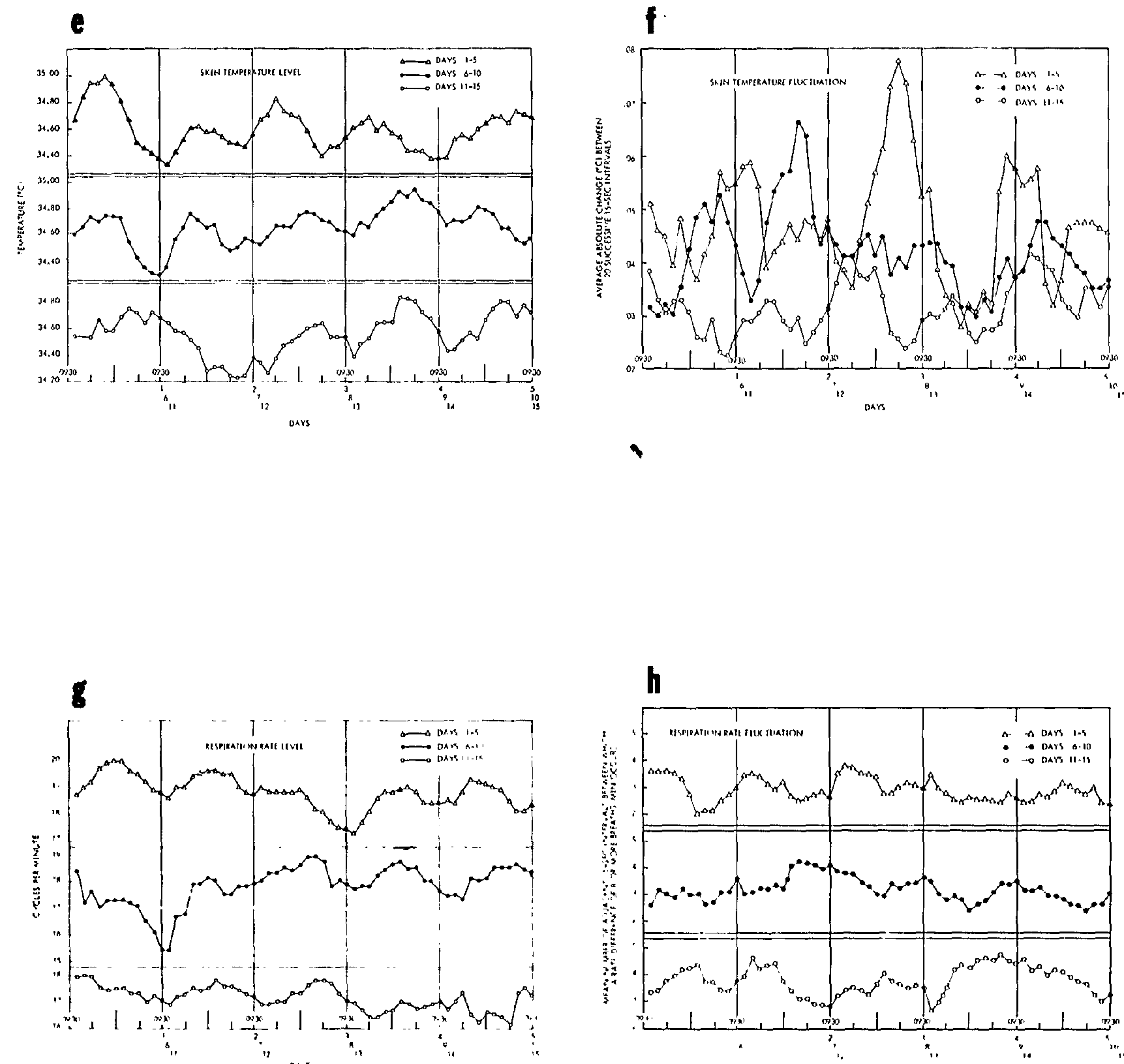

Figure 8 (E through H). Mean level and mean fluctuation for the psychophysiological measures. See text for explanation of method used to derive points on the curves.

TABLE 4

Analysis of Variance by Ranks: Daily Levels of Psychophysiological Measures

Measure		Group	Chi-square	p-level*
Skin Resistance:	Level	A	49.73	.001
		B	38.42	.001
		A+B	79.92	.001
	Fluctuation	A	43.77	.001
		B	36.95	.001
		A+B	66.92	.001
Heart Rate:	Level	A	45.27	.001
		B	25.71	.05
		A+B	57.11	.001
	Fluctuation	A	11.46	--
		B	19.04	--
		A+B	12.51	--
Skin Temperature:	Level	A	16.66	--
		B	8.26	--
		A+B	10.46	--
	Fluctuation	A	17.56	--
		B	7.11	--
		A+B	18.42	--
Respiration Rate:	Level	A	25.96	.05
		B	19.49	--
		A+B	39.49	.001
	Fluctuation	A	14.79	--
		B	16.79	--
		A+B	15.21	--

*df = 14.

TABLE 5

Correlation (Rho) of Each Subject's Rank-Ordered Daily Psychophysiological Measure With Days of the Study

Group	Subject	Skin Resistance		Heart Rate		Skin Temperature		Respiration Rate	
		Level	Fluc.	Level	Fluc.	Level	Fluc.	Level	Fluc.
A	S-1A	.89	-.57	-.75	.00	-.29	.00	-.35	-.03
	S-2A	.97	-.56	-.91	-.03	-.17	-.12	-.66	-.22
	S-3A	.35	-.12	-.78	-.15	.31	.18	-.84	.76
	S-4A	.83	-.91	-.62	-.59	.41	-.23	-.50	.63
	S-5A	.95	-.34	-.72	-.02	-.52	-.08	-.12	-.29
B	S-1B	-.35	.14	-.45	-.33	-.44	.14	**	**
	S-2B	.22	-.93	-.02	-.20	-.65	-.44	-.12	.03
	S-3B	.74	-.76	-.16	.15	.19	-.08	-.30	.18
	S-4B	.81	.01	-.22	.66	.45	-.30	-.85	.77
	S-5B	.72	-.61	-.84	-.47	.01	-.53	**	**
	S-6B	.78	-.64	-.48	-.08	.75	-.78	-.45	-.26

.05 Level: rho = .44 (one-tailed test)
.01 Level: rho = .62 (one-tailed test)

** Recordings too poor to give reliable measures

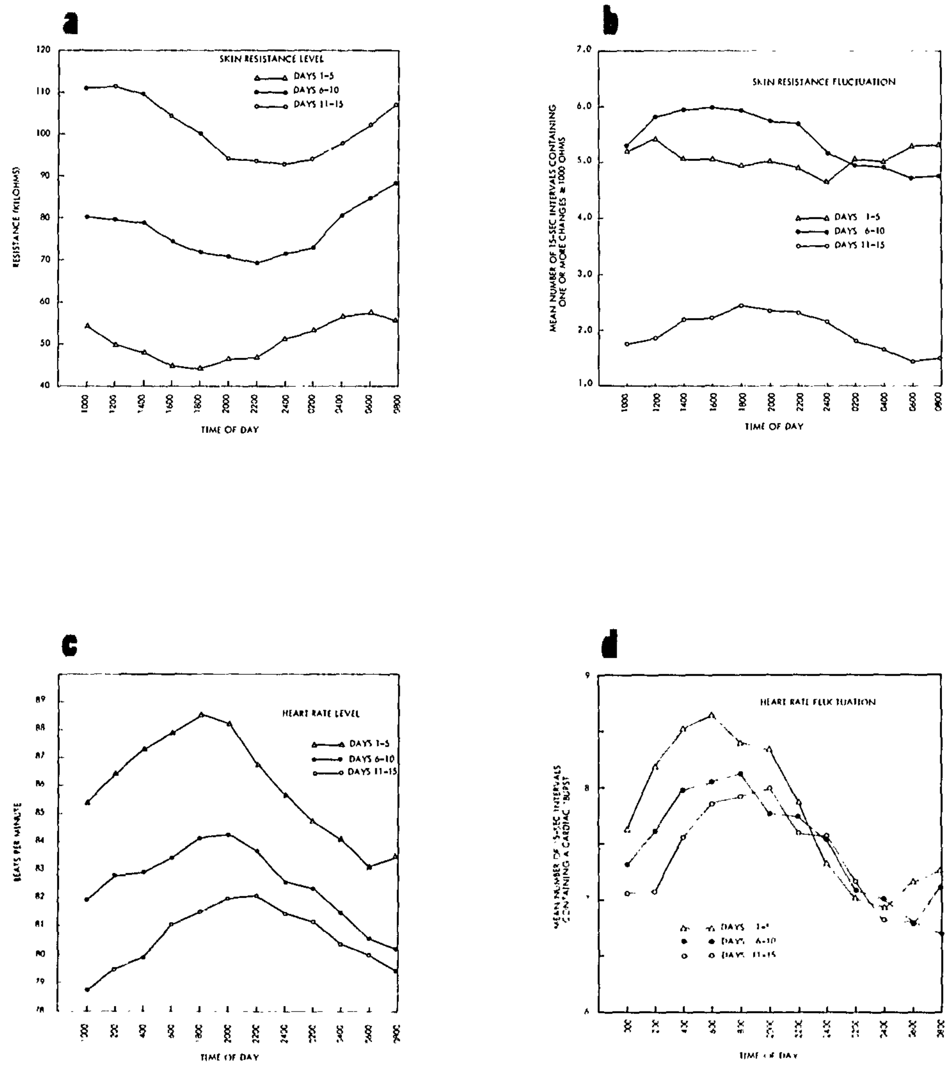

Figure 9 (A through D). Within-day changes in level and fluctuation scores for the psychophysiological measures

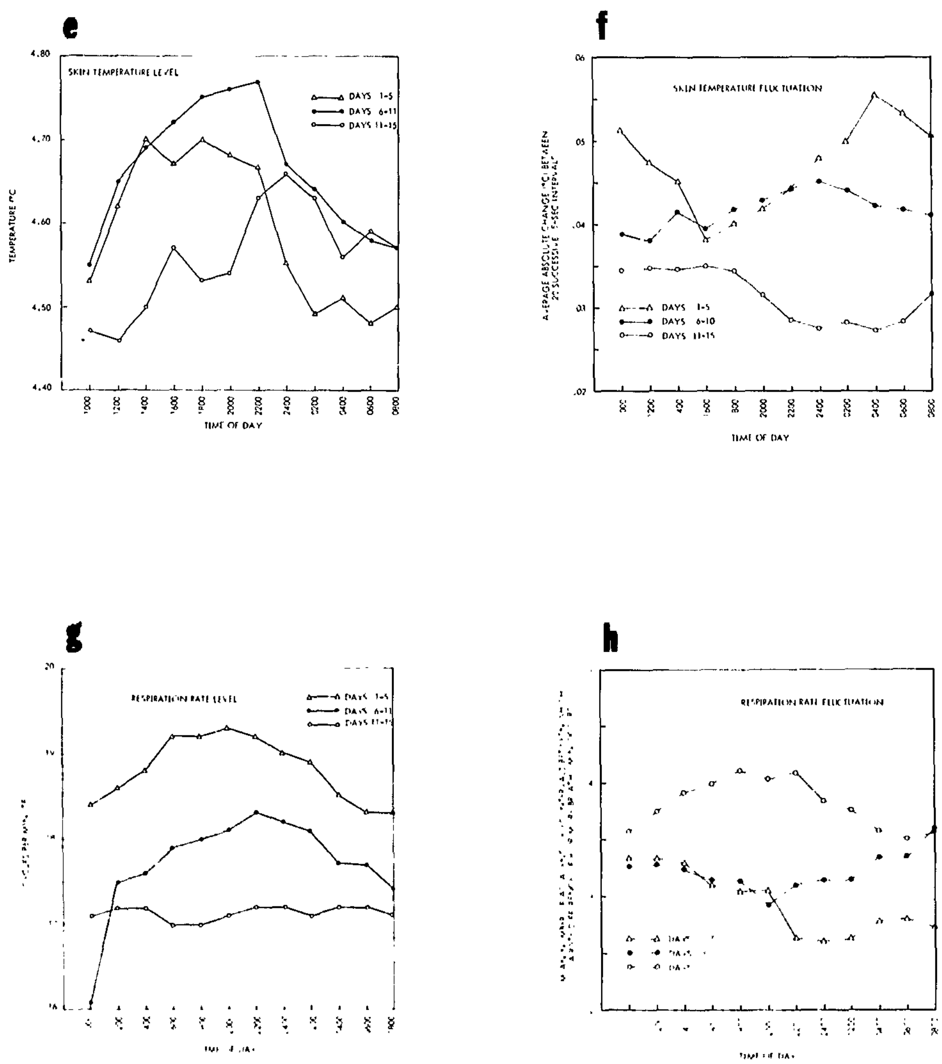

Figure 9 (E through H). Within-day changes in level and fluctuation scores for the psychophysiological measures

Because these curves were derived from the "rolling mean" scores, they were not subjected to a statistical analysis. However, the consistency with which the within-day changes occur strongly suggests that, for the subjects tested, they are beyond chance expectation.

GENERAL QUALITATIVE OBSERVATIONS

Only the general qualitative results for Group B will be considered since this was a volunteer group, and significant changes were made in the operating procedures after the testing of Group A.

The general attitude expressed by these subjects, both before and after the test, was that, though somewhat unusual, this was just another mission which they intended to carry out as directed. Although all of the subjects indicated that they felt their performance to have suffered at times because of tiredness, only once did it become apparent that a subject had fallen asleep while on duty, and this did not occur until the 14th day of the test. Four of the subjects indicated in the post-test interviews that they had been able to get enough sleep. Five of the subjects expressed the opinion that they could have performed their normal crew duties on this schedule, and 4 of these 5 felt that they could have continued their performance indefinitely. All but one of the subjects indicated that they would be willing to undergo the experience again, and this one subject said he would do it again if it were of value to the Air Force to have him personally serve as a subject. This particular subject appeared to be unable to adjust to the altered sleep-wakefulness routine and reported that he had suffered increasingly from sleep deprivation as the confinement period continued.

DISCUSSION

In presenting the results of the 15-day tests, an attempt has been made to show the effects of the 4-2 schedule on both individual and group trends in performance. This approach was followed in order to take into account the rather obvious differences in group as well as individual levels of motivation. We knew, for instance, that Group A was a non-volunteer crew and that Group B had volunteered for the assignment. We believe that this factor should be given important consideration in assessing between-group differences in the levels and trends of performance, such as those shown in figures 5 and 6.

Another question which is raised by the 15-day test results concerns the extent to which performance was affected by variables inherent in the tasks (e.g., monotony and repetition) as opposed to the physical factors of the work-rest schedule (e.g., minimum sleep and disruption of the normal diurnal rhythm). There is a distinct possibility that these task characteristics attenuated the trends of improvement for some subjects and accentuated the trends toward decrement for others above and beyond the effects of the work-rest schedule *per se*.

A subsequent study, summarized in Appendix II, was undertaken to obtain "control" data by examining the performance of a group of 6 subjects (students) who were tested 4 hours a day, 5 days a week, for 6 weeks. They were free to spend the remaining hours of each day at their normal residences and to engage in their customary work, study, or rest activities. At the end of this period each subject had accumulated a total of 120 hours of task performance. Although this represents only one-half the number of hours of performance accumulated by a subject in the 15-day study, it was considered sufficient to obtain a fairly good estimate of performance trends.

For each of the task criteria the performance trends for the Control Group have been compared with those for Group B during the first 120 hours of performance, spread over the first 7-1/2 days (180 hours) of the 15-day confinement test.* (See figure 11 and table 7 of Appendix II.) Each data point for Group B is based on 4 hours of performance for all 6 subjects. In clock time successive points for Group B represent successive quarters of days with 0930 as the starting point of a day.

One subject in the Control Group experienced considerable initial difficulty on the arithmetic task (but only on this task) to the extent that his performance depressed the Control Group mean well below that of Group B (figure 11-A). When this subject is eliminated the curves for the two groups suggest roughly equal initial performance levels, but there appear to be divergent trends of the curves over time. The performance of the 5 remaining subjects in the Control Group showed significant improvement over days whereas that of Group B showed a consistent, though not significant, decline over days (table 7).

The performance of both groups improved significantly on the pattern task, (figure 11-B) and a single smoothed curve would fit both sets of data points. Since there was a total of 380 pairs of patterns available for this task, given pairs were repeated approximately every fifth 45-minute performance period. There was ample evidence in the comments of the subjects that, as a consequence of this recycling of the program, specific pairs of patterns were being recognized, and the appropriate response was being learned from one appearance of a pair to the next. In addition, subjects were presumably learning improved approaches to the task. The equality of the performance of the two groups suggests that the widely-spaced work periods and relief from the confinement situation (Control Group) did not facilitate learning of the sort found with this task.

The performance of the Control Group on the probability monitoring task, as measured by percent detections, was somewhat more erratic and at a slightly lower level than that of Group B (figure 11-C). Detection time for this task was initially slower for the Control Group with a suggestion of improvement over time and, conversely, initially better for Group B with a suggestion of a decrement over time (figure 11-D). However, there was in general very little if any difference between the performance levels of the two groups on this task.

On the red warning lights the performance of the Control Group was superior to that of Group B with no readily apparent trends suggested (figure 11-E). On the green warning lights (figure 11-F) the Control Group improved significantly over time and was superior to Group B which, in contrast, continued to perform at approximately its initial level throughout the first 7-1/2 days of the confinement period.

In general, the Control Group was superior to Group B on the auditory vigilance task (figure 11-G), and, although the trend for neither group was significant, Group B showed a somewhat greater decrement than the Control Group.

Those tasks on which the Control Group was superior (viz, the arithmetic, red and green warning lights, and auditory vigilance tasks) have a common element in that they all demand primarily a state of alertness for successful performance. In general, the responses called for are simple and—especially in the arithmetic task—highly "overlearned." The pattern task, which was performed equally well by both groups, involved an important learning component in the familiarization with the pattern pairs as the number of repetitions progressed. The efficiency of this learning process appears not to have suffered from the rigorous schedule imposed on Group B. A possible explanation for this sustained performance of Group B can be derived from the fact that on this task the subject can readily perceive improvement in his performance,

*Group A was not included in the comparison for the reason that, unlike the subjects in Group B and in the Control Group, they were non-volunteers.

and, perhaps more important, can see that it is possible for him to further improve his performance by learning the patterns. The perceived improvement and the obvious technique for attaining further improvement would serve as an important source of motivation not readily apparent in the other tasks.

The psychophysiological measures (recorded only in the 15-day study) offer support to the generally held notion that psychological variables, such as alertness, are functionally related to the level of activity of the autonomic nervous system. Although there are no immediately obvious correspondencies between the levels and trends of these measures and those of the performance tasks for individual subjects, there are some indications of relationships between the group means for the psychophysiological and performance data. In this respect curves for skin resistance level (figure 8-A) and for heart rate level (figure 8-C) are to a marked degree similar to those obtained for probability monitoring (figures 4-C and 4-D) and for auditory vigilance performance (figure 4-G). In each case the daily group means are fairly stable for the first 5 days, increase (or decrease) steadily over the next 5 days, and finally level off during the last 5 days. A similar trend was observed (not plotted in this report) in Group A's performance of the warning lights monitoring task which is the only other instance of a between-day effect occurring with the "monitoring" task measures (see table 1).

The curves for both the performance (figure 4) and the psychophysiological measures (figure 8) exhibit a marked within-day effect, or diurnal variation. Although the amplitude of this 24-hour rhythm appears to diminish somewhat during the latter portion of the 15-day period, it obviously remains as a distinct periodicity. The major operational significance of this variation is that, since the points are based on data from all subjects, each curve can be interpreted as representing variations in the around-the-clock status of the system with respect to the particular parameter presented. Whether selection and training techniques could be used to minimize the diurnal effect produced by this particular work-rest schedule is, of course, not known. This possibility is sufficiently important, however, to warrant further investigation.

The fairly consistent tendency for the times of highest within-day level of performance and autonomic activation to shift from the early evening to the late evening or early morning hours during successive days is believed to be an artifact. Both tests were begun at 0930 hours which was approximately 3-1/2 hours after waking. As the study progressed, the subjects used 0930 as a reference point for the beginning of each day and thought of that time as corresponding to their normal hour of arising. In this sense, the subjects gradually shifted to a "time zone" which differed from that of the external environment.

In conclusion, we interpret the sustained performance of two of the subjects in Group B (table 2, S-4B and S-5B) to suggest that, with a minimum amount of selection from a population that has been previously screened (as is the case with Strategic Air Command crews), operators can be found who will maintain acceptable performance levels on a 4-2 schedule for periods as long as 15 days. And, since the majority of the subjects indicated in the post-test interview that they could have continued the test for at least another 15 days if it were necessary and important to do so, the total period of satisfactory performance could likely be extended to 30 days. The validity of generalizations made from this suggestion is necessarily constrained by factors such as representativeness and size of our subject samples. However, this sampling limitation is mitigated to a large extent by the fact that the only screening of subjects exercised beyond that employed by the Strategic Air Command was the criterion that the subjects be available for the study. Current Air Force programs suggest that very extensive selection procedures will be applied to the recruitment of operators for aerospace vehicles. Thus, the subject sample which we used would be expected to yield a rather conservative estimate as regards the performance capabilities of a population of potential astronauts. An additional mitigating factor is the high reliabilities yielded by the large number of repeated observations made on each subject over a prolonged period of time.

SUMMARY

The effects of a high-demand work-rest schedule on human performance and psychophysiological functioning were studied using USAF operational personnel (two B-52 crews) who were confined to a small-volume crew compartment for a period of 15 days. Crewmembers followed an around-the-clock work-rest schedule of 4 hours on duty and 2 hours off duty. During the 4-hour duty periods each subject performed 5 tasks (arithmetic computation, pattern discrimination, probability monitoring, warning lights monitoring, and auditory vigilance) which were displayed on an operator panel located at the individual work stations. A specially designed bioelectric harness worn by the subject permitted the measurement of skin resistance, heart rate, skin temperature and respiration rate concurrent with task performance.

When the performance scores of all subjects were combined, a significant between-day effect was obtained for 4 of the tasks. Three (arithmetic computation, probability monitoring, and auditory vigilance) of these reflected a trend toward decrement, and one (pattern discrimination) was associated with an improvement in performance. Over the 15-day period a significant within-day effect (diurnal variation) was observed in all performance tasks.

A significant between-day effect was obtained for the measures of 3 psychophysiological variables (skin resistance, heart rate, and respiration rate). In each case the daily trend in these measures was that of a decrease in the level of autonomic activation (i.e., an increase in skin resistance, and a decrease in heart rate and respiration rate). All four of the psychophysiological measures showed a prominent within-day effect although the method used for deriving specific scores precluded the use of a statistical test for significance.

Although wide between-group and between-subject differences occurred in the scores for both performance and psychophysiological measures, it is concluded that with a minimum amount of selection, highly motivated crews can maintain acceptable performance levels on a 4-on and 2-off schedule for a period of two weeks and possibly longer. This suggestion is supported by several observations made during the present study. First, there were two subjects who were able to maintain a high performance level throughout the duration of the study. It was felt that this was, to a great extent, a function of their high level of motivation. Second, 7 of the 11 subjects showed a significant improvement with time in their performance of a learning task (pattern discrimination). The hypothesis that widely-spaced work periods would facilitate improvement on this task could not be substantiated from the results of a subsequent control study. And third, in a post-test interview, the majority of the subjects indicated that they could have continued the test for at least another 15 days if it were necessary and important to do so.

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APPENDIX I

FOUR-DAY TESTS

METHOD

Subjects

The subject sample consisted of 20 male college students who were enrolled in the Georgia Institute of Technology, Emory University, or Georgia State College. They had completed an average of 9-1/2 quarters of college work and the typical subject was beginning his senior year. They ranged in age from 19-1/4 to 26 years; their height range was from 5 feet 7 inches to 6 feet 2 inches; and their weights ranged from 135 to 192 pounds. Each had volunteered to participate, and each was paid for his services.

The experimental design required that subjects be tested in 4 groups of 5 subjects each. Upon arrival each subject was asked to indicate his previous association with the other members of his group by checking one of the three following statements: (a) Never met before; (b) Know casually; (c) Know very well. Sixteen of the 20 subjects stated that they had never met another member of their respective group. The remaining four (two pairs) said they knew each other casually.

Test Facility

Subjects were tested in the 5-man, advanced system crew compartment mock-up which is described in the main body of this report. During the 4-day period only the work-station and leisure areas were used. Occupancy of the leisure area was restricted to those times when a meal was served while a subject was on duty and to occasional use of the toilet facility. With these two exceptions all other off-duty activities were limited to rooms located near the one containing the mock-up. A leisure-area room was used at regular off-duty mealtimes, and individual sleeping bunks were provided in an adjoining soundproof room.

Performance Measures

The same 5 performance tasks which were used during the 15-day studies were utilized throughout the present investigation. The tasks (described in Appendix III) are designated as follows: arithmetic computation, pattern discrimination, probability monitoring; warning lights monitoring, and auditory vigilance.

PROCEDURE

Experimental Design

The 20 subjects were divided into four groups of 5 subjects each. Two of the groups were tested separately on an around-the-clock schedule of 4 hours on duty and 2 hours rest for a period of 96 hours. The other two groups were tested separately for the same length of time on a schedule of 6 hours on duty and 2 hours rest. Within each test group the work-rest cycles of individual subjects were staggered, but never by more than 2 hours. At the end of the 4-day period, subjects on the 4-2 schedule had accumulated a total of 64 hours of work which was distributed among thirty-two 2-hour periods, and subjects on the 6-2 schedule had accumulated a total of 72 hours of work which was divided into thirty-six 2-hour periods.

Task Program

The 2-hour task program shown in figure 3 (p. 4) was used during the testing of all groups, and was presented 48 times during each of the four 4-day tests. The subjects were alerted to the beginning of the high performance period and to the change from the arithmetic to the pattern task by an intercom message from the experimenter.

Orientation and Training

Approximately 1-1/2 hours of the first day, a Friday for each group, were spent in the orientation of the subjects. The purpose was threefold: (a) to provide a general description of the training and testing routine, (b) to inform the subjects of the ground rules to be observed during the tests, and (c) to impress upon the subjects the importance of the study and the need for their cooperation. They were told that the study would directly affect future Air Force decisions concerning the assignments of optimal work-rest schedules during advanced flight missions and that it was necessary for them to approach the test with a serious attitude and a sense of responsibility. They were told that it was important that each subject organize his off-duty time, particularly during the first 48 hours of the test. Subjects were reminded that the experimental schedule would impose a change in their normal diurnal cycle and that they should try to get as much sleep as possible during the 2-hour rest periods. They were encouraged to ask questions, make comments, and state any complaints they might have during the course of the study.

Following the orientation, subjects were given instructions for performing the individual tasks. After it had been ascertained that they understood the instructions, they were required to perform the 2-hour task program. On the following Monday they were given three hours of practice with the high performance portion of the task program. Thus, each subject received a total of 5 hours of training prior to beginning the 4-day period of testing.

Testing

The subjects of a given group reported to the Laboratory at 0700 hours on a Tuesday, at which time each was issued a lightweight summer flight suit and given a bunk assignment in the sleeping quarters. As soon as these details had been completed, 4 subjects were designated to go on duty immediately in the crew compartment. Testing commenced at 0730 hours and continued until 0730 hours the following Saturday.

Incidental to the actual performance testing, the subjects were required to abide by the following regulations and procedures related to the test conditions:

(a) Fifteen minutes prior to going on duty, subjects were alerted and told to report to the leisure-area room. One minute before commencing the duty period they were escorted to the mock-up by one of the experimenters.

(b) All meals were furnished by the Laboratory. A daily menu from the company cafeteria was posted, and subjects were allowed a free selection of foods. Orders were taken one meal ahead, and individual food trays were delivered to the leisure-area room at specified times. If a subject on the 6-2 schedule were on duty during a meal hour, the meal was placed in the food compartment of the mock-up. The subject was permitted to leave his station during the 30-minute low-performance period of the task program to eat his meal at the small fold-away table located in the aft section of the crew compartment.

(c) During the 30-minute low-performance period of the task program, subjects were allowed to use the toilet facility in the mock-up, provided they requested permission over the intercom. Only one subject at a time could be away from his station.

(d) Subjects were restricted to specific rooms of the Laboratory and were not allowed to place or receive telephone calls.

(e) Hot coffee, hot chocolate, milk, fruit juices, light snacks, reading material, checkers, chess, and cards were available at all times in the off-duty leisure area.

RESULTS

The 4-day trends obtained with both work-rest schedules on each of the 7 performance measures were presented in figure 10. Each data point represents the mean taken during successive 2-hour work periods of the 4 days of testing.

It is immediately apparent that the two schedule groups were not equated with respect to their performance during the first day. Because of this, the only comparison that is appropriate is in terms of differences in between-day trends. An analysis of variance of the rank-ordered means of subjects by days for each of the task measures is given in Table 6.

TABLE 6

Analysis of Variance by Ranks: Daily Levels of Task Performance

Task Measure	Group	Chi-square	p-level*
Arithmetic Computation	4-2	2.55	--
(Number of Correct Answers)	6-2	9.96	.02
Pattern Discrimination	4-2	8.28	.05
(Number of Correct Responses)	6-2	17.85	.001
Probability Monitoring	4-2	4.47	--
(Percent Correct)	6-2	2.91	--
Probability Monitoring	4-2	10.20	.02
(Detection Time)	6-2	3.12	--
Warning Lights Monitoring (Red)	4-2	8.76	.05
(Reciprocal of Response Latency)	6-2	4.32	--
Warning Lights Monitoring (Green)	4-2	3.00	--
(Reciprocal of Response Latency)	6-2	3.00	--
Auditory Vigilance	4-2	0.36	--
(Percent Correct)	6-2	8.76	.05

*df = 3.

Except for the warning lights task, the level of performance for subjects on the 4-2 schedule was consistently lower than the level achieved by the subjects on the 6-2 schedule. Both groups showed decrements, however, with certain criteria. The 4-2 groups showed a decrement in scores for probability monitoring detection time and for red warning light response latencies. For the 6-2 groups, performance deteriorated on the arithmetic and auditory vigilance tasks. The performance gain on the pattern discrimination task is the only instance in which both groups showed a significant difference among daily means on the same task.

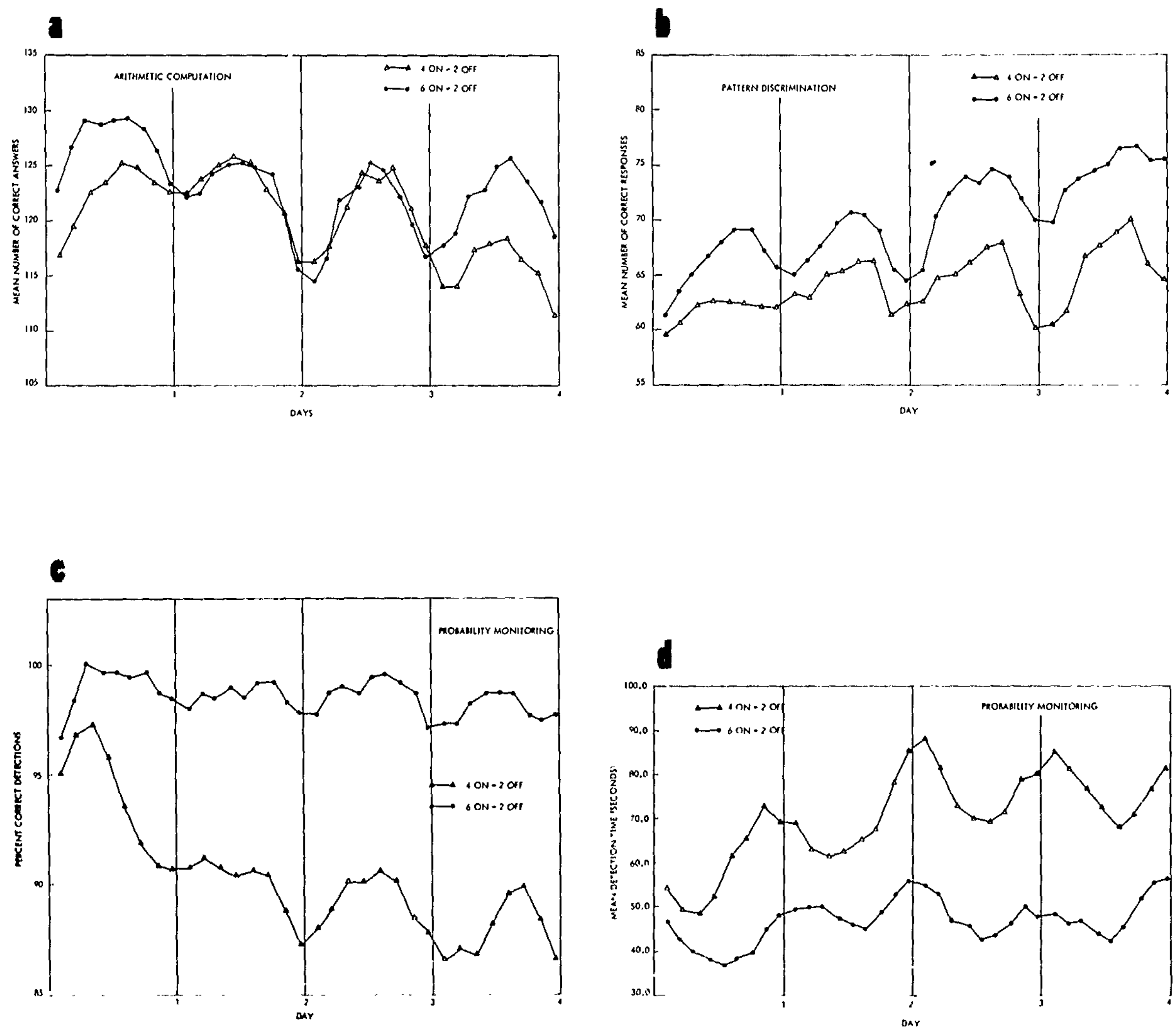

Figure 10 (A through D). Comparison of the 4-2 and 6-2 schedule groups in terms of trends in mean performance levels

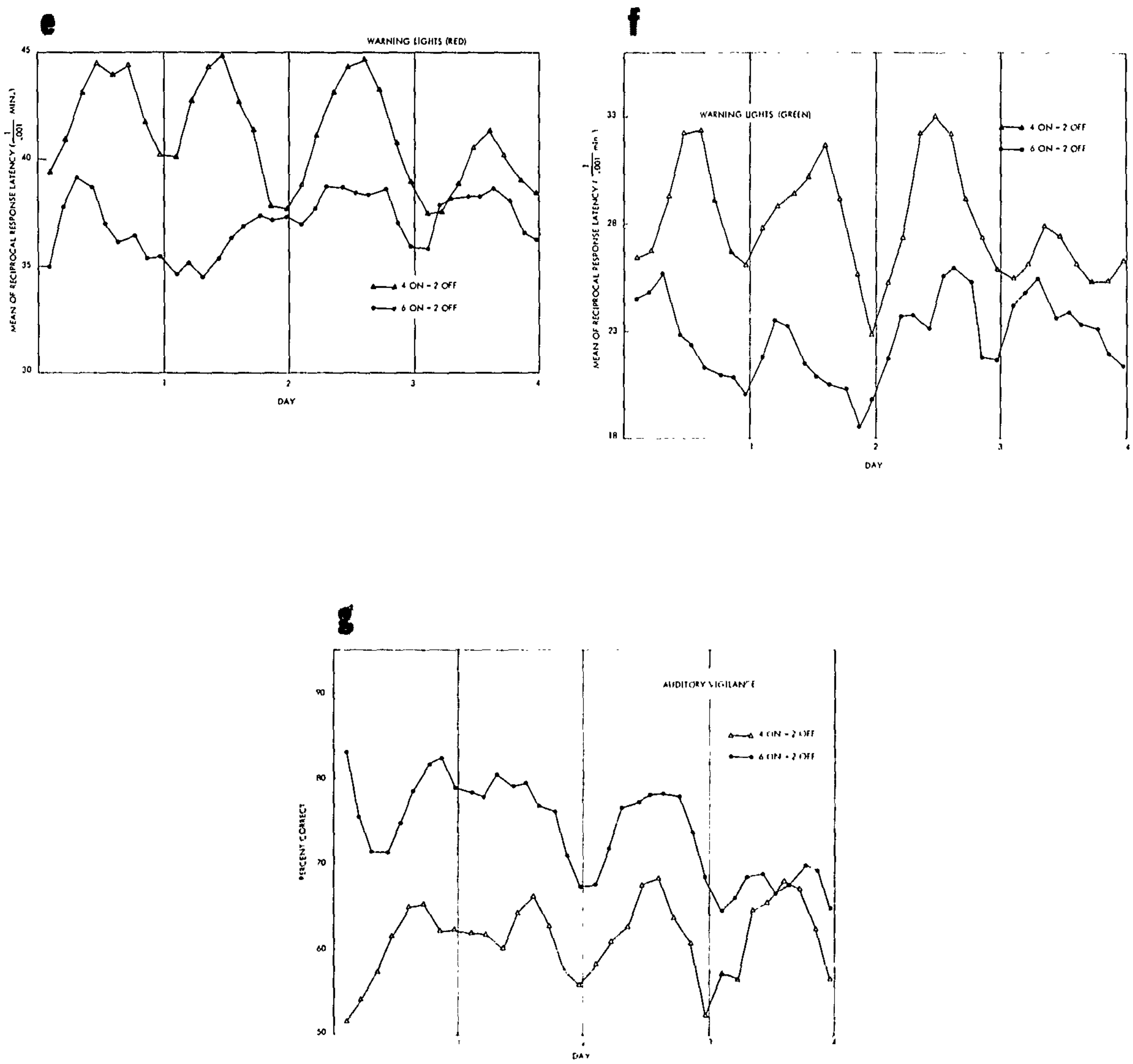

Figure 10 (E through G). Comparison of the 4-2 and 6-2 schedule groups in terms of trends in mean performance levels

In addition to the between-day trends, a fairly prominent within-day change (diurnal variation) was present in the performance of both schedule groups on all task measures.

The subjects in the 4-2 study averaged 5-1/2 hours of sleep per day, whereas those in the 6-2 study averaged less than 4 hours per day.

APPENDIX II

CONTROL STUDY

METHOD

Subjects

The subject sample initially consisted of 10 male college-level students who were either enrolled in or had completed their training in a school or university located in the Atlanta area. During the course of the study, 4 subjects withdrew for personal reasons unrelated to the test, and as a result only 6 of the 10 subjects completed the testing. The majority of the original 10 had no previous association with each other, and the average subject knew well no more than one other person in the test group. None of the 6 subjects who completed the study had any previous association with another. All of the subjects employed had volunteered to participate, and each was paid for his services.

Test Facility

All testing was conducted in the 5-man, advanced system crew compartment simulator which is described in the main body of this report. The test facility, without modification, was the same as that employed during the 15-day confinement studies.

Performance Measures

The 5 performance tasks which were used during the 15-day studies were utilized throughout the present investigation. The tasks (described in Appendix III) are designated as follows: arithmetic computation, pattern discrimination, probability monitoring, warning lights monitoring, and auditory vigilance.

PROCEDURE

Experimental Design

The 10 subjects were divided into 2 groups of 5 subjects each, and each group was tested separately for a total of 120 hours of performance per subject. Testing was conducted for 4 hours a day on 5 consecutive days (Monday through Friday) for 6 consecutive weeks. One group was tested during the morning hours (0745 to 1145) and the other during the afternoon hours (1200 to 1600) throughout the study. During the remaining hours of the day and the days of the weekend, the subjects were free to pursue their normal study, work, and rest activities.

Task Program

The basic 2-hour task program illustrated in figure 3 (p. 4) was presented twice each day to each of the test groups.

Orientation and Training

Approximately 1-1/2 hours of the first day, a Thursday, were spent in orientation of the subjects. During this time the experimenter provided a general description of the training and testing routine, explained the ground rules to be observed during the tests, and emphasized the importance of the study and the need for cooperation. Following the orientation, the subjects were given instructions for performing the individual tasks. The last 1-1/2 hours on Thursday and the entire 4-hour session on Friday were spent practicing the task program. Testing began on the following Monday.

RESULTS

The performance data of the 6 subjects who completed the control study were averaged for each of the 4-hour test sessions, and the levels and trends of the means of measurements made on the different sessions (30-day trends) were tested for significance. The performance curves obtained for each of the task criteria are presented in figure 11.

The mean number of arithmetic problems correctly computed by the Control Group on each day of the study is represented by two of the three curves shown in figure 11-A. The lowest curve (solid circles), which is based on the data of all 6 subjects, indicates an unusually low performance level at the onset, followed by a somewhat slow but consistent improvement during the first 13 periods (days). An examination of the performance of individual subjects revealed that this initial depression of the curve could be attributed to the performance of a single subject (S-6). Consequently, the period means were recomputed to reflect the performance level attained by the other 5 subjects. The result of this operation is shown in the uppermost curve (open triangles). This is the only task for which an individual's performance significantly affected the group trend, and it is not known why this subject's initial performance was so poor on this particular task.

In the case of each task measure the level and trend of performance obtained by the Control Group are compared with those obtained by Group B during the first 120 hours of the 15-day confinement study. The results of this comparison, in terms of an analysis of variance by ranks and also in terms of rank-order correlation coefficients, is presented in table 7. To perform the analysis for the Control Group data, a ranking was made of each subject's weekly performance (the mean of the five 4-hour sessions). To obtain equivalent scores for the analysis of Group B's data, a ranking was made of the mean performance each subject attained during 6 successive 30-hour blocks, each containing ten 2-hour sessions.

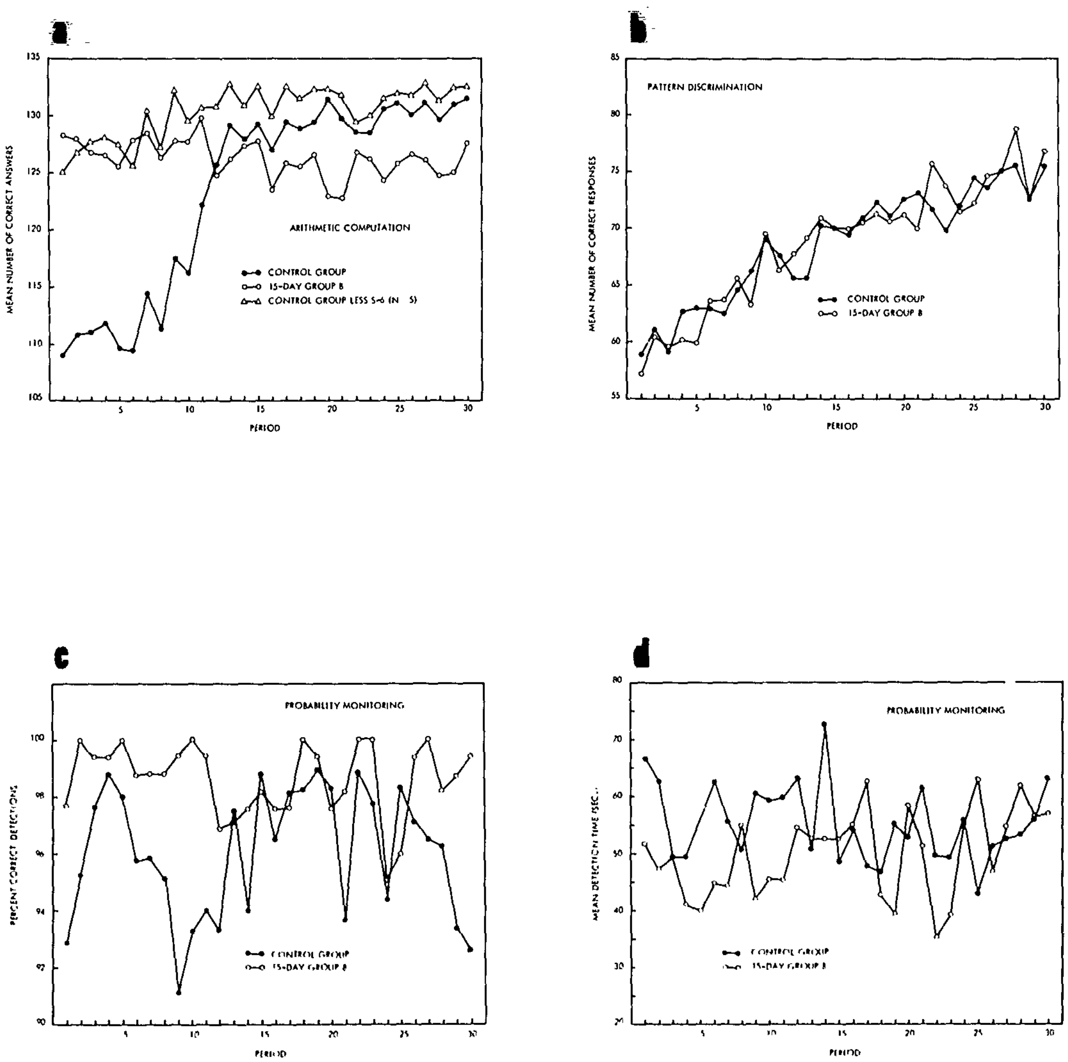

Figure 11 (A through D). Comparison of the Control Group and Group B (15-day study) in terms of trends in mean performance levels

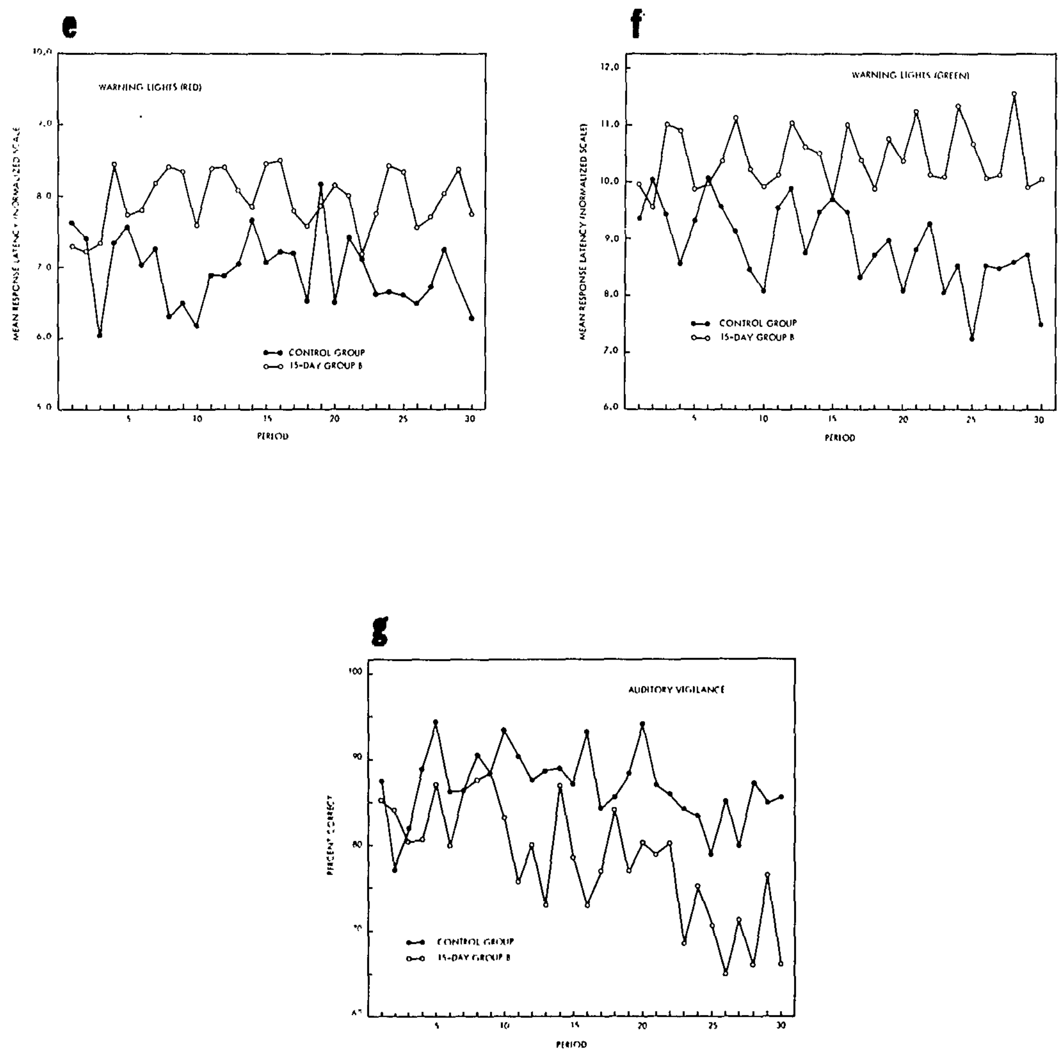

Figure 11 (E through G). Comparison of the Control Group and Group B (15-day study) in terms of trends in mean performance levels

TABLE 7

Comparison of the Control Group and Group B in Terms of Levels of Task Performance (Analysis of Variance by Ranks) and in Terms of Trends in Group Mean Scores (Rho)

Task Measure	Group	Chi-square	p-level*	Rho**
Arithmetic Computation	Control	21.75	.001	.92
(Number of Correct Answers)	(Control)***	(21.11)	(.001)	(.73)
	B	5.05	--	-.48
Pattern Discrimination	Control	19.08	.01	.95
(Number of Correct Responses)	B	27.24	.001	.95
Probability Monitoring	Control	3.04	--	.09
(Percent Correct)	B	1.12	--	-.13
Probability Monitoring	Control	5.85	--	-.23
(Detection Time)	B	4.00	--	.39
Warning Lights Monitoring: Red	Control	7.95	--	-.26
(Response Latency)	B	9.43	--	.05
Warning Lights Monitoring: Green	Control	14.32	.01	-.58
(Response Latency)	B	3.93	--	.13
Auditory Vigilance	Control	4.35	--	-.35
(Percent Correct)	B	6.19	--	-.71

*df = 5

**P-level:	.05	.01
one-tailed test	.31	.42
two-tailed test	.36	.46

***Less S-6

APPENDIX III

DESCRIPTION OF PERFORMANCE AND PSYCHOPHYSIOLOGICAL MEASURES

PERFORMANCE MEASURES

A battery of five performance tasks designed to test psychological functions, such as mental computation, pattern discrimination, monitoring, and vigilance, was used in both the 4-day and 15-day tests. The tasks were displayed on an 11-by-28 inch panel (see figure 2, p. ↄ) which was mounted at each work station in the crew compartment mock-up. The specific tasks, discussed in detail in previous reports (Adams, ref. 1; Adams & Chiles, ref. 2) are briefly described as follows:

Arithmetic Computation - Three 3-digit numbers were displayed along the lower central portion of the instrument panel by means of nine 1-digit numerical indicator tubes. The subject was required to subtract the third 3-digit number from the sum of the first two. The answer was indicated by manipulating a three-level concentric dial and toggle switch located at the lower right portion of the panel. Movement of the switch automatically recorded the response as being right or wrong. If the answer was correct, a blue light was illuminated on the subject's panel as soon as the problem had been removed from the display. From a basic program of 560 problems, 135 were presented at a constant rate of three per minute. The criterion measure was the number of problems each subject solved correctly during 45 minutes of performance.

Pattern Discrimination - The display for this task consisted of a 6 x 6 matrix of lights mounted in a 4-inch square array at the lower left corner of the subject's panel.

For a given 45-minute period, a punched tape programmer (containing 380 different pairs of patterns) presented 90 pairs at a constant rate of 2 pairs per minute. The first member of the pair was presented for 5 seconds, followed by a 5-second off period. The second member of the pair, always rotated 90°, 180°, or 270° from the orientation of the first member, was then presented for 5 seconds. Following this second presentation the subject was given 15 seconds in which to indicate whether his judgment was "same" or "different" by throwing a 3-position, spring-centered toggle switch in the appropriate direction. A correct response turned on a blue light on the subject's panel. The criterion measure was the number of correct responses made during 45 minutes of performance.

Probability Monitoring -This task was displayed by means of four semicircular scales located along the upper portion of the panel. A pointer on each scale was driven by a random program generator; the pointer settings were normally distributed with a mean of zero (12 o'clock position) and a standard deviation of 25 scale units. The introduction of an appropriate bias to the programming device shifted the mean of the distribution on a given scale 25 units to the right or left without changing the variance. A 52-step programmer provided a random presentation of 20 right, 12 zero, and 20 left biases and, on the average, introduced 9 biases during an hour.

When the subject suspected that a particular pointer was biased in a given direction, he moved the toggle switch associated with that dial in the suspected direction, whereupon the pointer moved to the mean of its distribution, i.e., a reading of -25, 0, or +25. If a bias was present, release of the switch reset the system to a zero-bias condition and the program continued. At the end of each 5 minutes a record was made of whether a bias which may have been present was detected, the number of false responses, and the time required to detect a bias if introduced.

Warning Lights Monitoring - This task consisted of 5 red and 5 green jewel indicator lights which were located in pairs on both sides and in the middle of the panel. The subject was required to turn any given green light on, if it went off, and any red light off, if it came on, by pressing the appropriate pushbutton located beneath the light in question.

An average of 10 non-normal indications, 5 red and 5 green, were presented at random during an hour's performance. The subject's latency in responding to each non-normal indication was recorded on a 0.001-minute timer. If he failed to respond within two minutes the non-normal condition was automatically corrected by the program apparatus, and the time was recorded as 2.000 minutes.

Auditory Vigilance - The input for this task consisted of a continuous series of "beeps" from an 1175-cps tone generator. This beeping tone, presented once every 1.05 seconds through a single earphone worn by the subject, was normally on for 0.25 second, and off for 0.80 second. The critical signal to be detected was a single off-period of 1.30 seconds which occurred 8 times per hour. When the subject thought that he had detected this change, he turned a spring-loaded knob which was located at the edge of his instrument panel. He was not provided with knowledge of results as was the case in the other tasks.

The number of correct responses and the total number of times the subject had turned the answer knob were recorded. In order for a response to be scored as correct, the subject had to respond within 30 seconds after the occurrence of a critical signal.

PSYCHOPHYSIOLOGICAL MEASURES

Each of the four psychophysiological measures selected for use in this study has been discussed in a previous report (Adams, Levine & Chiles, ref. 3). The measures are described briefly in the following paragraphs.

Skin Resistance - Skin resistance was measured by the Fels Dermohmeter which used a direct current of 70 microamperes through the volar surface of the finger tip, returning through a ground located on the homolateral forearm. The finger electrode was a zinc disc, 20 millimeters in diameter, to which was affixed an oval, sponge corn pad. The hole in the pad was filled with a firm bentonite, water and glycerine paste containing 1% NaCl, and the electrode was held in place, pad side toward the finger, by a plastic Band-Aid. In this way, the area of contact with the finger surface was well controlled; the foam and Band-Aid insured a firm, unmoving, yet comfortable attachment. The arm electrode was a sterling silver sheet, 5 x 5 centimeters in area, 0.7 millimeter thick, and curved to fit the forearm. The surface toward the arm was bounded by a 1/4 x 1/4 inch strip of gum-backed polyurethane foam forming a shallow reservoir. This reservoir was filled with a semiliquid paste of bentonite, water and glycerine containing 3% NaCl. The electrode was covered on its back side by a sheet of gum-backed 1/8 inch polyurethane foam, cut to fit, through which protruded two short stubs designed to fit the holes of an electrocardiographic arm strap. This arrangement provided a comfortable, low-resistance electrode which was non-irritating to the skin even when worn 16 hours a day for 15 days. Because of a tendency of electrodes to polarize after carrying direct current, each use of the electrodes in a skin resistance measurement was followed by application of the same current reversed, for a similar length of time. (This reduces polarization and continues to do so almost indefinitely.)

Two measures were chosen to characterize each 5-minute interval of record. The first of these was a "level" measure; it consisted of the mean of 20 instantaneous values of resistance, one for each 15-second subinterval of the recording interval. The second was a "fluctuation" measure; it was the number (from 0 to 20) of 15-second subintervals in which at least one galvanic skin response occurred, i.e., a decrease in resistance of 1000 ohms or more which occurred within a 3-second period and which exhibited smooth initial and final changes of slope.

Skin Temperature - The Yellow Springs Instrument Company Telethermometer was used to measure skin temperature. The sensing element was a thermistor bead embedded in a 3/8 inch diameter button which had a flat, thermally conductive surface toward the skin and a convex insulating surface on the opposite side. The button was held against the forehead by means of a head band containing a padded pocket into which the thermistor fitted. It touched the skin through a hole in the pocket.

Two measures were used to characterize each 5-minute interval recorded: the arithmetic mean of the temperature during the 5 minutes (measured each 15 seconds), and the variance of the changes from one 15-second reading to the next. The former score was taken to characterize the level of skin temperature; the latter was a measure of fluctuation.

Heart Rate - The Fels Cardiotachometer measured the duration of each individual cardiac cycle (R-R interval) and presented its reciprocal as a meter reading which was calibrated directly in beats per minute. The cardiotachometer input was the subject's electrocardiogram obtained from two active electrodes plus a reference (ground) electrode.

The active electrodes were oval sheets of fine silver, 3.0 and 4.4 centimeters on minor and major diameters, and 0.2 millimeter thick. To each electrode was affixed a bunion pad of the same shape. The hole in the pad was filled with a paste of bentonite, water and glycerine containing 3% NaCl. The electrode was covered on its back side by a sheet of gum-backed 1/8 inch polyurethane foam, cut to fit; two short stubs, designed to fit the holes of an electrocardiographic chest strap, protruded through the foam pad. The strap was placed around the chest at the level of the 4th intercostal space at the sternum. Two electrode locations were chosen for each individual subject so as to pick up the largest possible unidirectional cardiac voltage, thereby maximizing the reliability of the recording. The reference electrode for the system was the skin resistance ground electrode described earlier. Electrocardiographic electrodes of the type described are comfortable and non-irritating to the skin even when worn 16 hours a day for 15 days.

Two measures were taken to characterize each 5-minute interval of recording; heart rate level and heart rate fluctuation. Auxiliary counters tallied the individual beats for precisely 5 minutes; the heart rate level was taken as one-fifth of this number, i.e., the average number of beats per minute. The fluctuation measure was the number of "cardiac bursts" occurring during the 5-minute interval. A "burst" was tallied each time the maximum heart rate in a 5-second subinterval exceeds the maximum rate in the immediately preceding 5-second subinterval by 6 beats per minute or more. Successive tallies were not counted unless separated by at least 5 seconds. Thus the fluctuation measure can theoretically take integral values from 0 to 59. However, in practice, the heart rate does not continually increase by 6 beats per minute per 5 seconds for more than about 20 seconds at a time.

Respiration Rate - A respirometer designed in this laboratory was used for the measurement of the breathing movements. It utilized information received from a pair of carbon buttons which were encased in a potting compound and placed in an elastic belt that held them against the subject's body. The buttons were alternately compressed and released by the respiratory motions of the abdomen or chest, and the resulting variations in resistance drove a meter, the movement of which followed the respiratory motions.

Two measures were used to characterize each 5-minute interval of record: respiration rate level and respiration rate fluctuation. The level measure was the average number of breaths per minute during the 5-minute interval and was obtained by counting the total number of breaths and dividing by five. The fluctuation measure was the number of changes in rate which occurred during the 5-minute interval. A rate change was tallied each time the number of breaths completed during a 15-second subinterval exceeded, or was less than, by at least two, the number completed in the immediately preceding 15-second subinterval. A rate change was not tallied if the counts in the two subintervals could be made equal merely by shifting the time position of the two subintervals by the equivalent of one breath or less. Successive tallies were not counted unless separated by at least 15 seconds. Thus the fluctuation measure could theoretically take integral values from 0 to 19.

ASD TR 61-720

Lockheed-Georgia Company, Marietta, Georgia
HUMAN PERFORMANCE AS A FUNCTION OF THE WORK-REST RATIO DURING PROLONGED CONFINEMENT, by O. S. Adams and W. D. Chiles, November 1961, 50p. incl. illus., tables. (Proj. 1710, Task 171002)
Unclassified report

The purpose of this study was to investigate the feasibility of using a 4-hours-on-duty and 2-hours-off-duty schedule in the operation of advanced aerospace systems. Two B-52 combat ready crews were confined for 15 days in a simulated advanced system crew compartment and were tested with a battery of five
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